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SCIENCE
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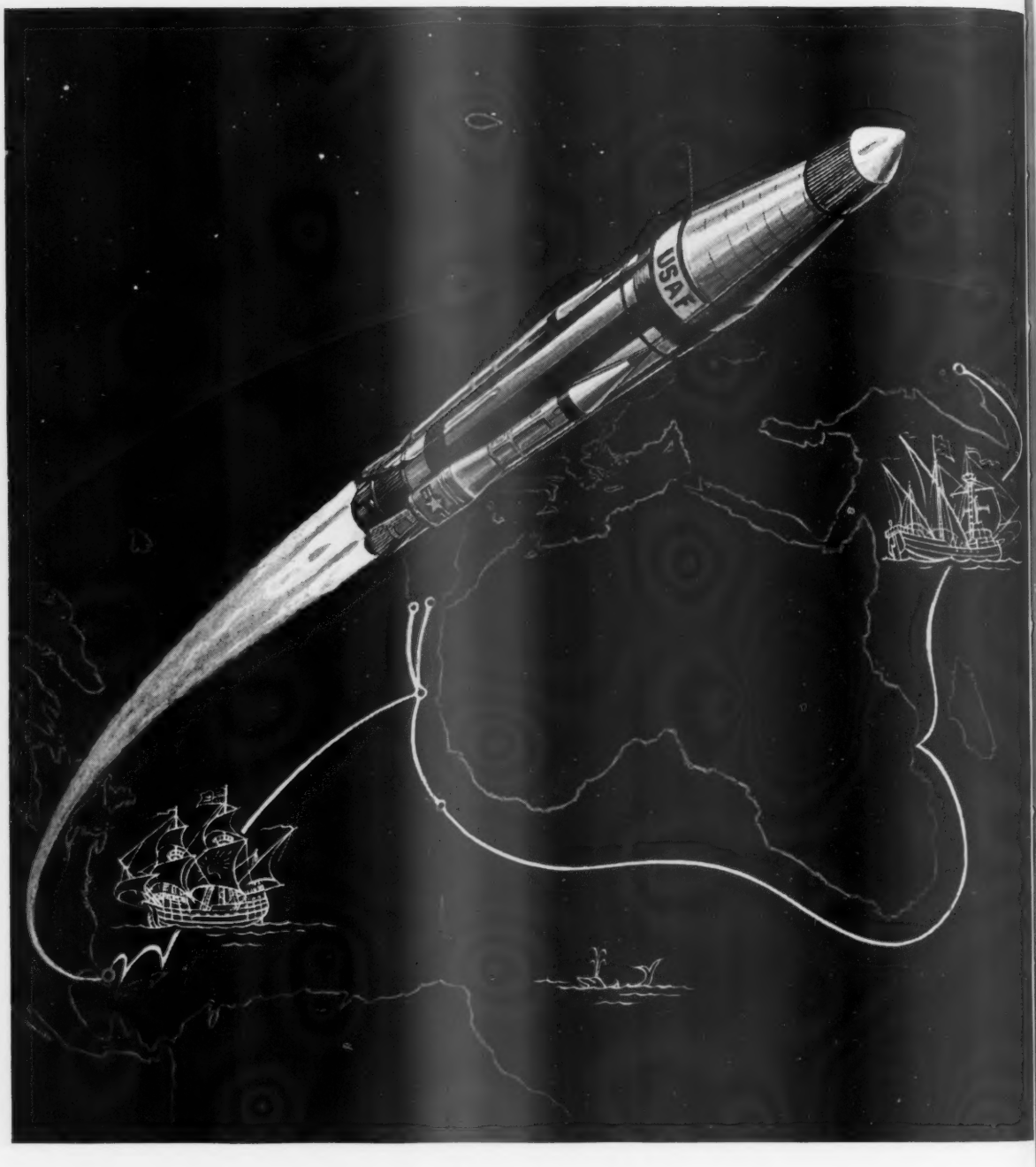

Arma navigates new routes

Navigating with cross-staff and primitive compass, Prince Henry's Portuguese pilots took more than 80 years to find a route around Africa and reach India. The Spaniards took another 20 years to cross the Atlantic and reach the shores of Florida.

Today, missile-borne inertial guidance can navigate such distances in a matter of minutes and pin-point targets nearly half-way around the world. Other advantages of inertial navigation are immunity to outside interference, all-weather capability, salvo firing, and a minimum of ground equipment.

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THERE IS SOMETHING NEW UNDER THE SUN

Yes, there *is* something new under the sun. Science is proving this every day. With new discoveries. New explorations. New concepts.

Nowhere is this more evident than in the field of technology. For example: On the drawing boards of Lockheed Scientists and Engineers, new designs are constantly being born—designs in Spacecraft and Aircraft that will reinforce and enlarge our growing knowledge of Outer Space.

These new designs are rapidly developing. And their number is rapidly increasing. The pace is fast. Yet it needs to become faster. To keep pace, Lockheed needs more Scientists, more Engineers. Result? The future for Lockheed was never more promising—the opportunities never greater.

Lockheed feels that trained men will do well to examine thoughtfully the Company's current openings. Notable among these are: Aerodynamics engineers; thermodynamics engineers; dynamics engineers; electronic research engineers; servosystem engineers; electronic systems engineers; physicists (theoretical, infrared, plasma, high energy, solid state, optics); hydrodynamicists; ocean systems scientists; physio-psychological research specialists; electrical-electronic design engineers; stress engineers; and instrumentation engineers.

Scientists and Engineers: To learn more about the opportunities at Lockheed, write Mr. E. W. Des Lauriers, Manager Professional Placement Staff, Dept. 2606, 2415 No. Hollywood Way, Burbank, California. All qualified applicants will receive consideration for employment without regard to race, creed, color, or national origin. U.S. citizenship or existing Department of Defense industrial security clearance required.

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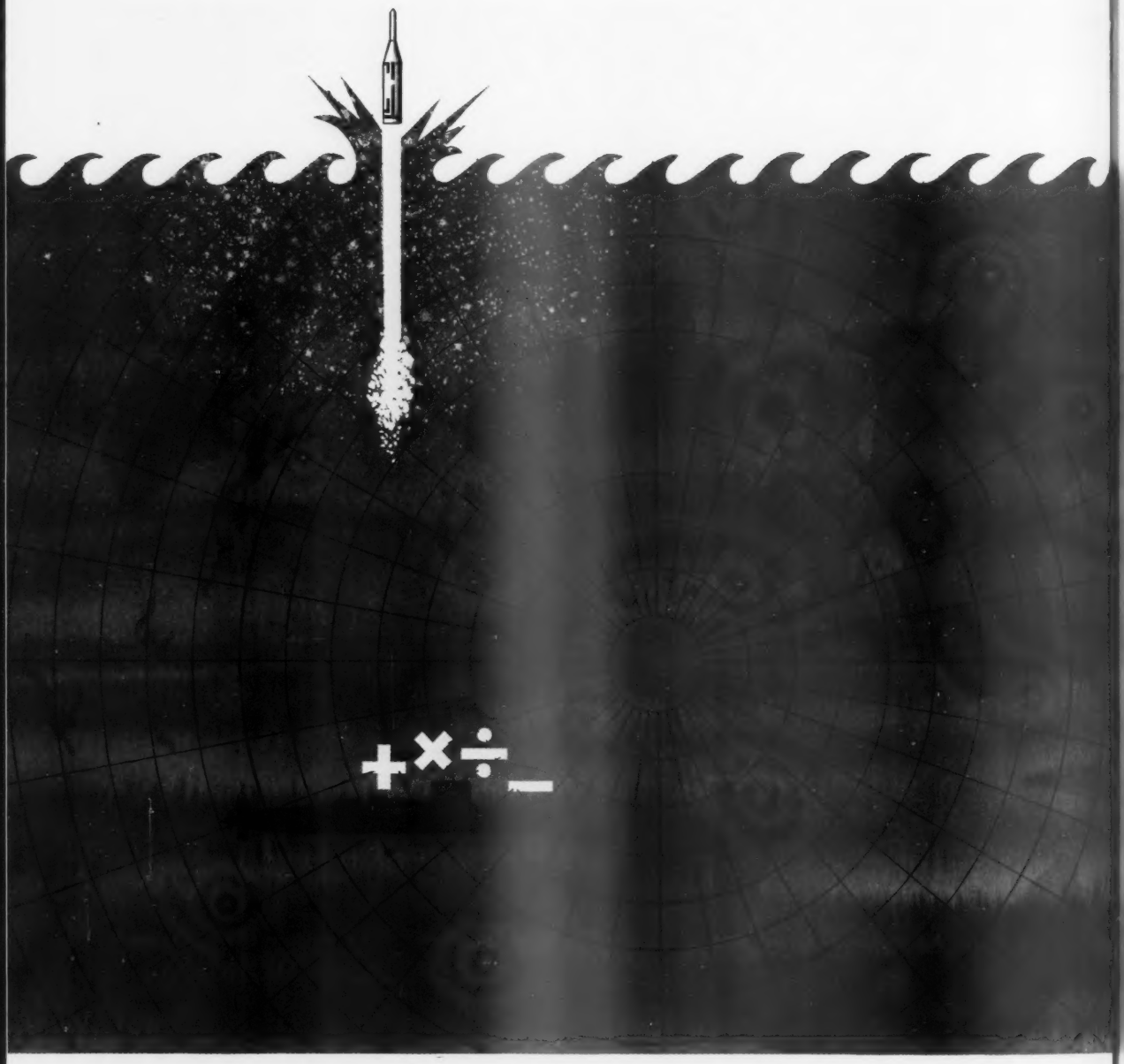

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at work in Polaris program

The mission: to develop and manufacture the electronic digital computer that provides stabilization for the submarine periscope or radio-metric sextant; resolves celestial information in bearing and elevation order signals; provides data for the correction of the inertial navigator; and compensates for the effects of roll, pitch, heading, and mast flexure. **The means:** Burroughs Compútence. **The results:** precise launchings for Polaris. **Other USN missions-accomplished:** Polaris Fire Control Switchboards, aircraft carrier landing systems (through Burroughs Control Instrument Co.), and advanced digital airborne computers. **The message:** Be it by land, sea, air or space, Burroughs Compútence—ranging from basic research through production to field service—takes its bearings, goes straight for the goal. Burroughs-TM

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AEROSPACE ENGINEERING

"Written Exclusively By Engineers—For Engineers"

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VOLUME 20 / NUMBER 6 **JUNE 1961**

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On our cover

Illustrating the *AEROSPACE SUPPORT* theme for this issue, an artist's conception shows the Silo Launch Test Facility (SLTF) for Titan II at Vandenberg AFB, Calif. On the third of last month—well after selection of the drawing for cover reproduction—the underground missile launching concept was proved by firing of a Titan from the Vandenberg site. The complex was designed and built by The Ralph M. Parsons Company, Engineers-Constructors, of Los Angeles, Calif., for the Air Force Ballistic Missile Division (ARDC) and Army Corps of Engineers (Los Angeles District). The SLTF is comprised of reinforced concrete control instrumentation center, steelframe equipment building, and fuel storage-handling facilities. The contractor's responsibility included design criteria, preliminary and final design and construction of the entire facility.

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Editor: **Allan Bernhardt, AIAS**

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BUSINESS STAFF

Business Manager and Advertising Production

John Phillips

Advertising Director

John R. Cockerell
116 So. Michigan Ave.
Chicago 3, Ill.
ANdover 3-6929

National Advertising Regional Offices

John Cockerell, Inc.

(Headquarters)
116 So. Michigan Ave.
Chicago 3, Ill.
ANdover 3-6929

3757 Wilshire Blvd.
Los Angeles 5, Calif.
DUnkirk 3-1135

380 Lexington Ave.
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Contributors are, however, urged to correspond with the *Editor* at any time during the review period whenever the need arises. Articles are published as rapidly as possible after acceptance. IAS, following the practice of other societies, does not pay for contributions.

Shown ⅓ actual size is a typical XBS modular system, utilizing a firing module, cabling, explosive cartridge, and a separation link. Of compact, solid state design, the firing module discharges two joules (one mfd at 2 KV) through an exploding bridgewire in less than 10 microseconds. Synchronizing circuits permit simultaneous initiation of multiple modules as required. This advanced XBS modular system provides important advantages of:

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6. Vernier igniters
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9. First stage destruct system
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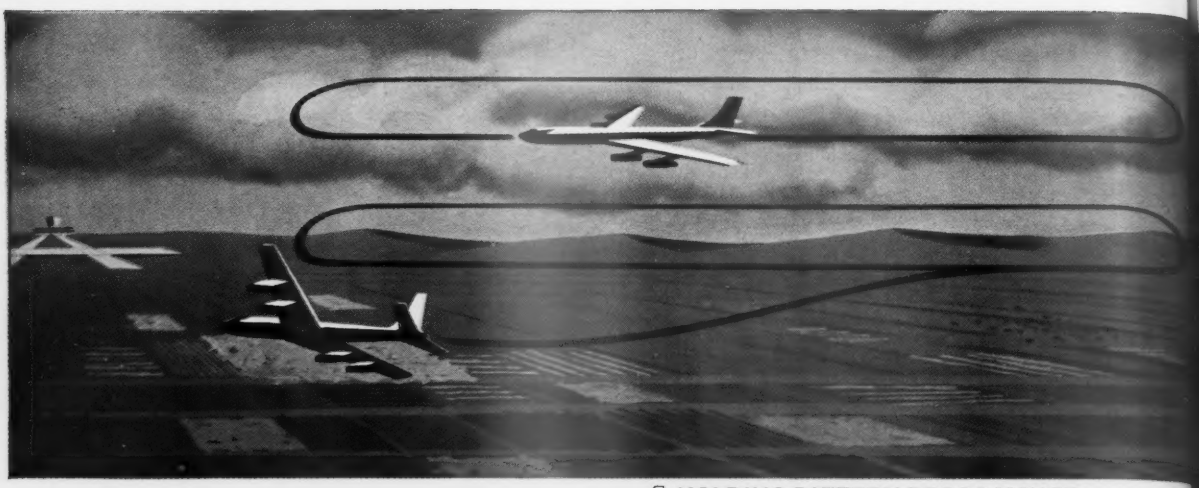

1 HOLDING PATTERN PROGRAMMER: Programs Automatic Flight Control System to fly prescribed holding patterns, automatically correcting for wind.

TRAFFIC CONTROL OF COMMERCIAL, MILITARY, AND BUSINESS AIRCRAFT TO BENEFIT FROM THESE 7 MODERN BENDIX AIRBORNE DEVICES

4 TO-FROM BEEPER: Gives audible signal during VOR station crossing, or at beam intersection, relieving pilot of tiring instrument concentration.

5 AUDIO CO-PILOT: An experiment in converting instrument flag warnings and selected flight data to audible signals (e.g.: calling out approach and take-off airspeeds).

2 VORTAC COMPUTER: Through airborne computation, creates phantom Vortac station where needed for parallel routing through congested areas and for direct flight navigation to destinations with limited navigation facilities. Provides constant readout of bearing and distance information.

Knowmanship in Action

Since introducing the "earth inductor" compass in aviation's early days, Eclipse-Pioneer has been responsible for a wide array of control and navigation equipment that has anticipated aviation's ever-growing, ever-changing needs. All seven devices shown on these pages are important new advances keyed to jet-age problems and ready to aid in relieving the cockpit pressures of navigation and traffic control.

TECHNICAL KNOWLEDGE + EXPERIENCED MANAGEMENT + SPECIALIZED CRAFTSMANSHIP = **KNOWMANSHIP**

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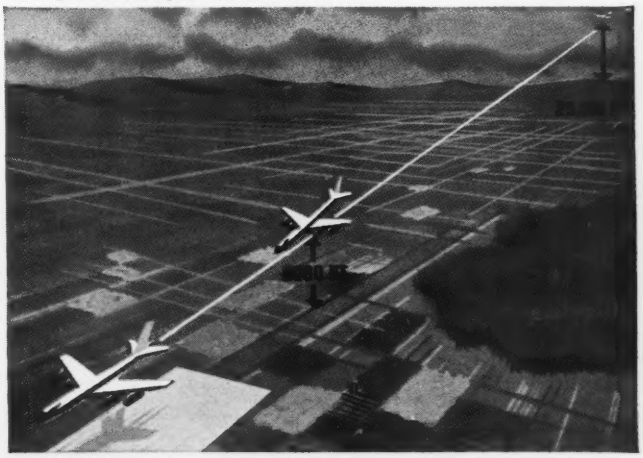
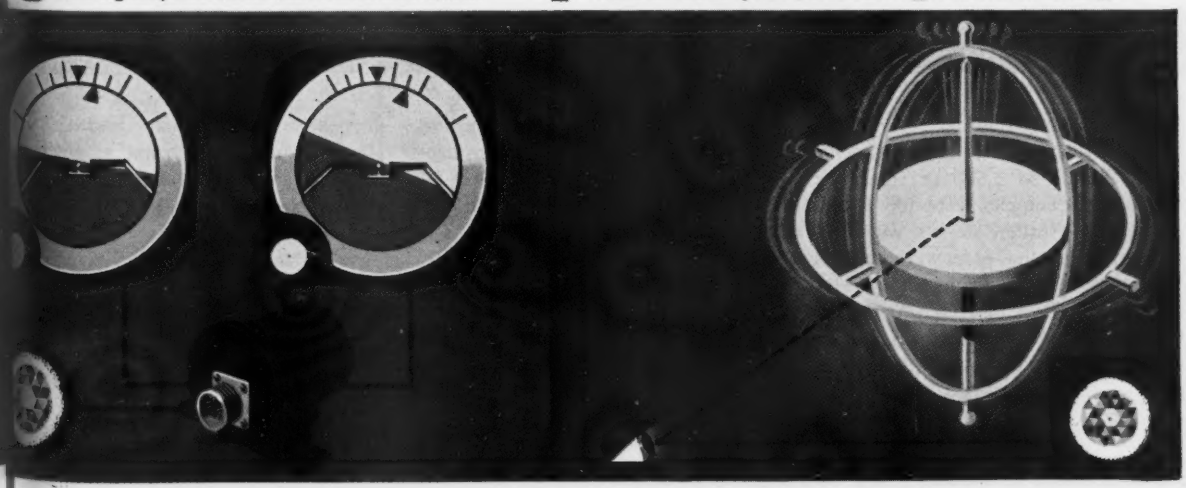
THE Bendix CORPORATION

3 VERNAV (Vertical Navigator): Automatically computes and flies optimum climb or descent path to any preselected point in altitude.

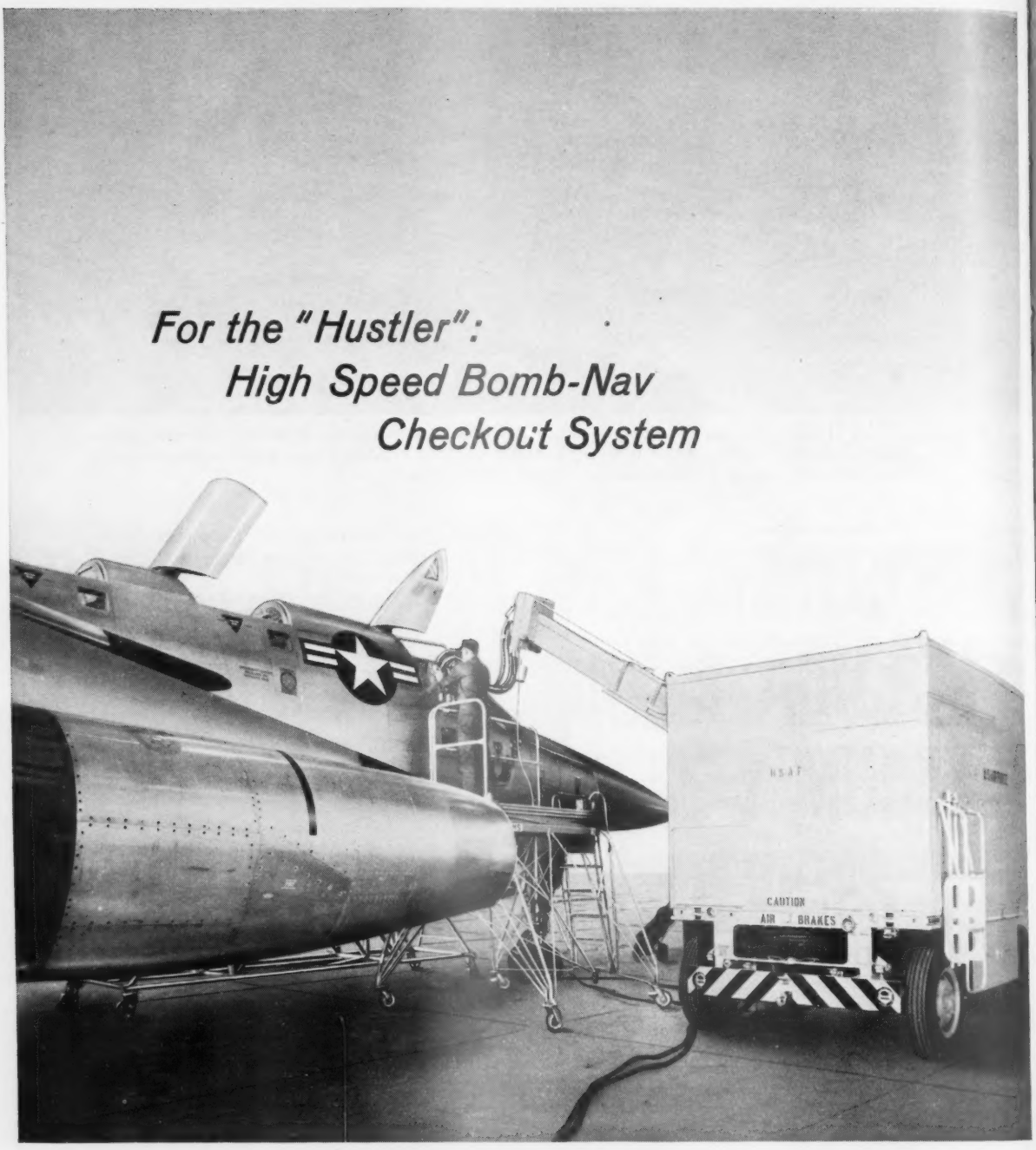


6 SIGNAL COMPARATOR: Compares signals from two like systems (i.e.: horizons, compasses, any synchro signals) and warns when difference exists.

7 TWO-AXIS GYRO MONITOR: Warns when gyro is not erected to vertical. When used with a Signal Comparator in a dual system, tells which gyro is malfunctioning.



For the "Hustler": High Speed Bomb-Nav Checkout System



A new, high speed automatic checkout system developed for Convair by Sperry can make up to 3,600 different line checks on the complex bomb-nav system of the B-58 Hustler, most of which require only 4 seconds to set and complete.

In a mobile van Flight Line Tester coupled to the B-58, the AGE (Aerospace Ground Equipment) performs desired checks which are programmed by punched tape. Visual "go, no-go" readout is provided. In event of malfunction, additional rapid automatic measurements are made in repair-shop installed test sets to pinpoint the trouble.

This advanced system is now undergoing final Air Force evaluations at Carswell AFB. Significantly faster than conventional checkout methods, the highly efficient Sperry AGE system also increases the accuracy, simplicity and flexibility of testing.

The Sperry-developed bombing-navigation system has contributed importantly to the newly operational Hustler, which won the SAC trophy for both low and high altitude bombing in 1960, with only 6 weeks of operational training for its crew.

SPERRY

AIR ARMAMENT DIVISION, SPERRY GYROSCOPE COMPANY, DIVISION OF SPERRY RAND CORPORATION, GREAT NECK, NEW YORK

This is IAS

An excerpt from a booklet by the same title to be published this month.

THE INSTITUTE of the Aerospace Sciences, a professional society for aerospace scientists and engineers, is the leading organization in its field. Founded in 1932, its basic aim is to advance the aerospace sciences by disseminating among its members technical information covering the entire range of human and automated flight. IAS interest ranges from ground hovering machines to jet aircraft and supersonic transports, from missiles to deep space probes and satellites. More comprehensive in scope than any other comparable organization in the Free World, the IAS embraces the state of the art both in its specific disciplines and in the sum total of the ways in which they relate to each other.

To help IAS Members fulfill their many-sided responsibilities, the Institute through its meetings, publications and other information services constantly updates knowledge and stimulates the skills of the individual scientist, engineer, administrator and others. It also provides recognition of professional standing by grading its membership against rigid educational and experience standards, and by granting awards for outstanding aerospace contributions.

Today, when the impact of aerospace science and technology upon the whole future of our society is becoming more crucial, the IAS serves as a communications bridge in bringing to the scientist and engineer the latest developments and trends in facilitating a continual cross-fertilization of ideas with those of their colleagues.

The very size and scope of IAS interests enable it to act as an international communications center and clearing house for ideas and information that arise from the scientific–technical community, from industry, universities, research foundations and the Government.

The IAS makes available to its members the most extensive aerospace library services in the Free World. It collects and distributes aerospace data from the earliest pioneer experiments to today's most sophisticated researchers at the frontiers of aerospace science.

The Institute takes the initiative in arranging joint meetings and symposia and otherwise cooperating with sister societies to encourage the pooling and dissemination of aerospace knowledge. It makes every effort to avoid duplication and waste of the country's aerospace mind power.

The IAS collaborates closely with the National Science Foundation, the National Aeronautics and Space Administration, the Federal Aviation Administration, the Research and Development Offices of the Army, the Navy and the Air Force, and appropriate Committees of the Congress to foster a constant flow of inter-communication between the scientific–technical community and Government agencies.

Helping to keep the individual scientist and engineer continuously up-to-date on the most significant advances in aerospace theory and practice, the IAS alerts top management to new and vital trends. This provides industry with new sources for economic growth and for diversification.

The Institute encourages aerospace education from high school through graduate school. It conducts an extensive program in colleges and in universities to stimulate the student toward professional awareness and the need for high standards of capability. It offers guidance materials to vocational counsellors to assist students in choosing careers and in preparing for their college years in a practical and constructive fashion.

Membership in any professional society is the hallmark of the man who genuinely respects his own vocation. He gains in professional stature from association with colleagues in his field. More importantly, however, he thereby helps to extend the effectiveness of his profession, as a whole.

Membership in the IAS, the professional society which concerns itself exclusively with the aerospace sciences, takes on special significance and responsibilities. Progress in the aerospace sciences is today increasingly inseparable from questions of national security, economic vitality and the ability of free men to flourish, or even survive.

It has always been IAS policy in arranging its programs and in editing its publications to keep ahead of the requirements of its members. This it will continue to do. It will continue to serve the professional interests of its members in all flight regimes "from Zero to Infinity."

The First Titan Hardened Facilities

Marvin J. Kudroff, *Daniel, Mann, Johnson, & Mendenhall*

"The Air Force goal was to have a facility available for occupancy by the Strategic Air Command, one that was invulnerable to thermonuclear attack, at such a time as the missile itself became operational."

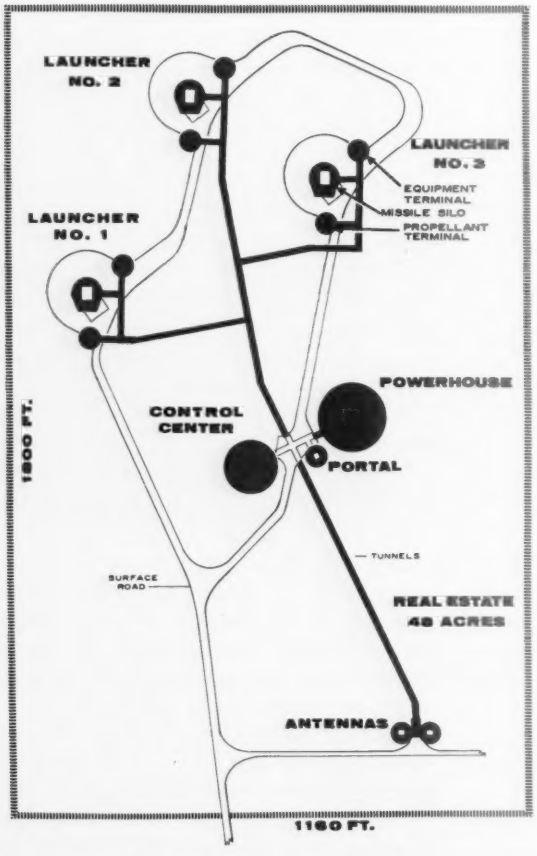


Fig. 1. Typical launch complex—a self-contained and completely self-sufficient operational unit.

In the Space Age this Nation's achievements in the missile and satellite fields are being exploited to the fullest. The engine thrust, propellant system, guidance system, electronic components, ground-support equipment, and the vehicle itself are truly great scientific achievements. Man in space is fast becoming a reality. Our international reputation and prestige are emphatically dependent on our success off the launch pad.

The greatest deterrent and our survival are emphatically dependent on our missile arsenal and its ability to provide immediate retaliation in the event of enemy attack. The problem confronting the Air Force therefore concerned not only the development of missiles, but also the determination of its ground environment and its vulnerability to enemy attack from both missiles and bombers. Its choice was mobility, dispersal, or hardening (resistance to thermonuclear attack). The Army IRBM, the Jupiter, was designed mobile with all equipment to support the missile, and the missile itself is trailerized. The Air Force IRBM, the Thor, is partially mobile with all ground-support equipment trailerized but with the missile and its propellant storage mounted to a fixed foundation. Next, the ICBM's, Atlas and Titan, were developed. They are much larger, heavier, and carry greater payloads than the IRBM. Because of difficulties in handling liquid propellants, these ICBM's cannot be considered mobile.

Studies were conducted on dispersal with its appropriate logistics support vs. hardening. The first Atlas squadrons were soft and dispersed; the first Titan squadrons were to be hardened and generally dispersed.

The hardening environment for these first Titan

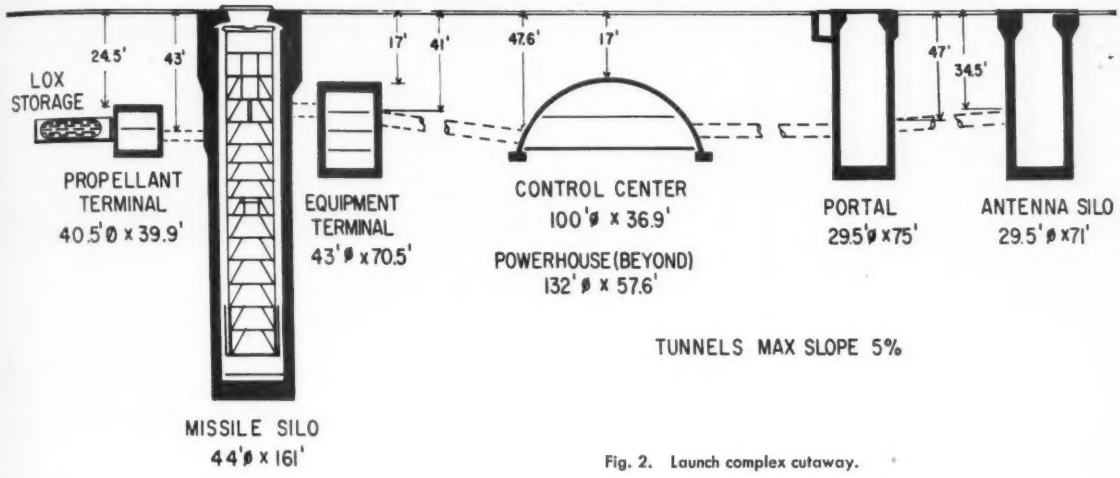


Fig. 2. Launch complex cutaway.

squadrons was established at 100 psi. With a minimum of criteria available, the Air Force set about selecting an architect-engineer for facility design. The scope—initial facilities construction cost in excess of $100 million; the available knowledge of the effects of nuclear weapons on buried structures—minimal; and the needs in the way of facilities to support the weapon system—undetermined.

In February 1958, 2 days short of 1 year before the first Titan became airborne, Daniel, Mann, Johnson, & Mendenhall and Associates (a joint venture consisting of DMJM of Los Angeles, Leo A. Daly Co. of Omaha, Mason & Hanger-Silas Mason Co. of New York, and the Rust Engineering Co. of Pittsburgh) were commissioned by the Air Force to be Architect-Engineer for the first operational squadrons at Lowry AFB, Denver, and the Operational System Test Facility (OSTF) and Training Facilities at Vandenberg AFB.

The challenge was tremendous. For the first time, this Nation's retaliatory forces, our ICBM's, would be just as dependent on A-E designed facilities as on the weapon itself. If, after nuclear attack of multimegaton magnitude (millions of tons of TNT), the facilities were damaged or transmitted loads to equipments that would cause them to malfunction, then the mission would be lost. Large equipment (such as diesel engine generators, propellant tanks and vessels, and air-conditioning compressors), as well as small equipment (such as circuit breakers, valves, pumps, and electronic signal devices and controls), are equally vulnerable to the tremendous accelerations and frequencies caused by the shock input. If damage were to occur to one important piece of equipment, large or small, the probability of launching a missile successfully would become uncertain. The Architect-Engineer therefore assumed the role of Associate Contractor, along with the Martin Co., AMF, BTL, Avco, and Aerojet.

Facilities, General

Each Titan I squadron consists of three separate complexes, each dispersed from 12 to 18 miles and each supporting three missiles. The first two Titan squadrons were located in the Denver area at somewhat closer spacing than noted above because of available Government-owned properties. The remaining four squadrons, for which DMJM and Associates designed two facilities, are located at Ellsworth AFB, Rapid City, S.D.; Larson AFB, Moses Lake, Wash.; Beale AFB, Marysville, Calif.; and Mountain Home AFB, Mountain Home, Idaho.

A launch complex consists of three launchers, each of which contains a missile silo, a propellant terminal, and an equipment terminal. The complex also contains a control center from which the missile is checked out remotely; a powerhouse which provides the power, air conditioning, water, and other utilities necessary to launch (*Continued on page 41*)

Mr. Kudroff received his B.S. in architectural engineering from Pennsylvania State University. He joined Daniel, Mann, Johnson, & Mendenhall in 1947 as a structural designer and since then has had management responsibilities on numerous military and industrial projects. He has successively held positions of Chief Structural Engineer; Project Manager on Rocketdyne's Engine Test Facilities and the Thor IRBM Training and Operational Facilities; Director of Engineering and Deputy Project Manager for DMJM and Associates on the Titan hardened facilities. He is currently Director of Special Projects for DMJM. Mr. Kudroff holds licenses as Civil and Structural Engineer in California and Professional Engineer in Colorado.

Vertical Floating

Lt. Comdrs. J. E. Draim and C. E. Stalzer, USN
U.S. Naval Missile Center (Point Mugu)

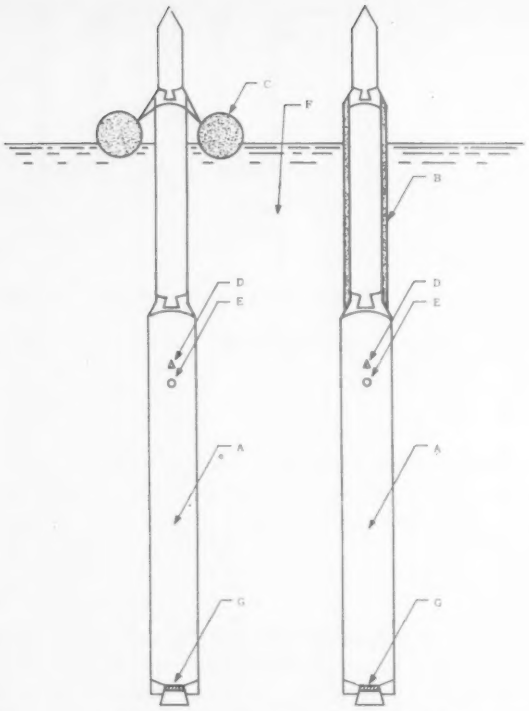


Fig. 1. Two methods of adding buoyant material to rocket for water launch. *A* is rocket vehicle, *B* is the buoyant jacket, *C* is the buoyant ring, *D* is the center of buoyancy, *E* is the center of gravity, *F* is water and *G* is the tail plug.

Commander Draim received a B.S. degree from the U.S. Naval Academy in 1949, a B.S. (aeronautical engineering) from the U.S. Naval Postgraduate School in 1955, and an M.S. from the Massachusetts Institute of Technology in 1956. His service in the Navy includes duty as first lieutenant of a destroyer and as a pilot and engineering officer in two carrier-based fighter squadrons. At the U.S. Naval Missile Center, Commander Draim has been associated with the Regulus II and Eagle missile programs, and with the Astronautics Research Division at the base. His assignment associated with Project Hydra began early in 1960.

Commander Stalzer received a B.S. degree in aeronautical engineering from the University of Notre Dame in 1953, an M.S. in aeronautical engineering from the Massachusetts Institute of Technology in 1954, and a Professional Engineering degree in aeronautical engineering from M.I.T. in 1955. His professional experience includes 3 years at the Boeing Airplane Co., where he worked on preliminary design of the 110-A weapon system (B-70), the DynaSoar, and the Minuteman ICBM. Commander Stalzer was stationed at the U.S. Naval Missile Center from September 1958 to January 1961 and became associated with Project Hydra early in 1960. He is currently assigned to the Directorate of Air Force Space Boosters, Air Force Ballistic Missile Division, U.S. Air Force.

The Navy announced on April 20 that Project Hydra now is ready for full-scale launching tests. On the day before, a 10-ton, 40-ft mockup of Hydra II was launched successfully from the ocean near Santa Cruz Island, thus advancing the project to the useful application stage.—*Editor*

PROJECT HYDRA was initiated at the U.S. Naval Missile Center, Point Mugu, Calif., early in 1960. Its objective is the development of sea-launched rocket vehicles and perfection of handling and checkout procedures. Briefly, the sea-launch concept involves floating the rocket vehicles vertically (in the manner of a spar buoy) on the surface of the ocean, and launching the rockets from this position.[1] Much of the expensive transportation, handling, erection, and servicing equipment necessary to conduct land launches is eliminated. The equipment used consists of standard tugs, floating dry docks, barges, and range instrumentation ships, none of which is limited in its capability of handling extremely large rockets of any foreseeable weight, size, or configuration. In the case of explosive malfunction at launch, the "launch pad" and other support equipment would not be damaged.

Prior to firing, the rocket vehicle is floating vertically, unmoored, in the water. Since most solid-propellant rocket vehicles have a specific gravity between 1.0 and 1.4, it is necessary to add some buoyant material (such as foamed plastic) to reduce the specific gravity of the combination to a value slightly less than unity. The distribution of this buoyancy must be controlled so that the rocket vehicle floats vertically prior to launch. This added buoyancy is jettisoned at launch. Two methods of adding buoyancy are shown in Fig. 1.

The three outstanding advantages of the (Hydra) water-launch concept are that:

(1) Mobility is unlimited over the surface of the oceans, allowing equatorial launches, and launches at arbitrary latitudes, to be carried out with relative ease.

(2) Handling requirements are simple, inexpensive, and a weak function of increasing weight.

Launch of Rocket Vehicles

Project Hydra—a study of handling, erection, acceleration effects, and checkout concepts applicable to water launch

Extremely large rocket vehicles weighing hundreds of tons may be transported, erected, and launched in the water with a minimum number of skilled personnel.

(3) Launch safety and range safety criteria may be satisfied by a suitable choice of launch site and by separation distances between rocket and support vessels at launch time.

A more complete comparison between water-launched and land-launched systems is presented in Table 1.

The development of the sea-launch concept should yield increasingly greater benefits as booster size increases. With the advent of nuclear rockets the techniques developed for water launch of large chemical rockets would prove invaluable. The hazards involved in the resting and operation of large nuclear rockets would be minimized by reason of complete isolation far at sea.

Vehicle handling techniques associated with the sea launch are discussed in this paper. The problems associated with system and component checkout are recognized, and various solutions are suggested.

Analytical and experimental results have been generated in water-launch investigations at the U.S. Naval Missile Center in the areas of (a) wave-induced motions of rocket vehicles floating vertically, and (b) mechanism of the vertical floating launch.

Sea-launch experimentation at the U.S. Naval Missile Center has been centered principally on solid-propellant rocket vehicles. In most respects, they are ideally suited to the water-launch concept. Storable liquid and hybrid rockets are promising, but cyrogenic liquid rockets (*Continued on page 46*)

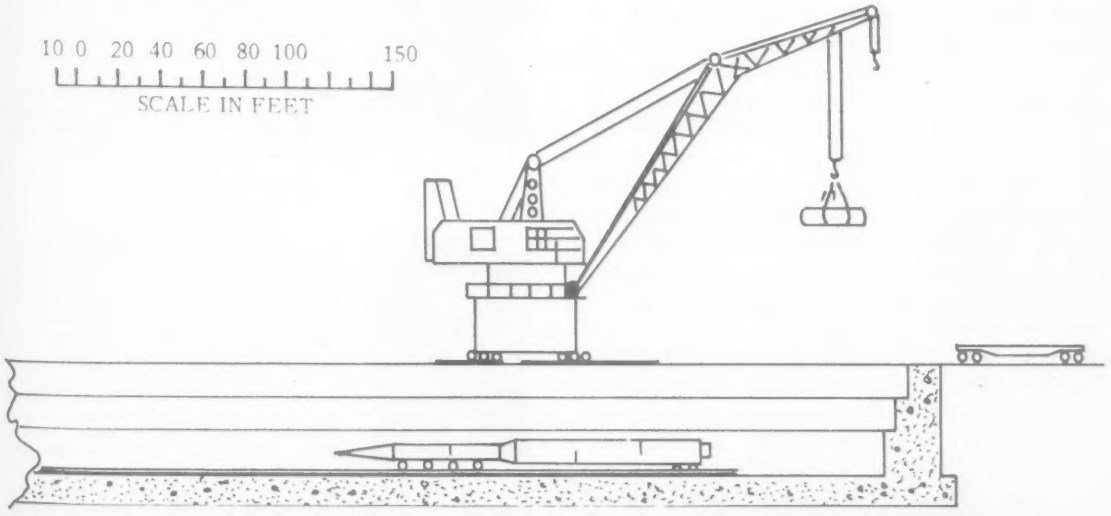


Fig. 2. Horizontal assembly of large solid-propellant booster vehicle by use of conventional dry-dock facilities.

Networks of Decentralized Decisions Under

R. W. Bragg, *Documentation, Inc.*
Edward B. Hincks, *Aerospace Industries Association of America, Inc.*

EACH NEW WEAPON system of the past decade has embodied advances in technology. The curve of technical complexity has increased sharply and the trend is continuing into space systems. To convert laboratory breakthroughs into operational vehicles requires the talents of many organizations. For a supersonic bomber (B-70) and supersonic interceptor (F-108), the North American Aviation Company works with 15 major subcontractors and, according to its President, J. L. Atwood, ". . . an estimated 20,000 companies will ultimately be involved. . . ."[1] For the solid fuel Polaris missile, Lockheed's Board Chairman, R. E. Gross, reported seven major industrial associates, and "in December 1958, 2,898 suppliers were supplying Lockheed or its subcontractors on the Polaris program."[2] Similarly, Convair reported 4,391 companies[3] involved in production of the Atlas ICBM, and Boeing, more than 3,600 companies[4] on the Bomarc interceptor missile system.

These companies in every sector of the American economy work together under a weapon system prime contractor (Fig. 1) to solve the technical problems each system poses. Advancing technology and delivering functioning equipment to the military services depends in part on how well they work together. This, in turn, depends in part upon the information available to management.

It is, to be sure, the technical and engineering capabilities that are searched out, in whatever company or location they may be, by the weapon system prime contractor in putting together the industrial team. Each new and changing team forms an industrial complex in which technological know-how, and hence technical decisions, are decentralized. With decentralized decisions, particularly in the technical realm of the product, there is an intensified need for effective central management; ". . . decentralized decisions work well only if the decision-makers at various levels can be given appropriate incentives and criteria. . . ."[5]

Information System

An information system, adapted to the industrial complex and the expected role of each participant,

Mr. Bragg, an industrial consultant, specializes in research and development programs. After attending Ohio State University, he served several years with Government R&D agencies, including the Research and Development Board, Office of the Secretary of Defense, and Naval Weapons Research and Development. He served as a key member of the organizing group in a number of new firms specializing in R&D. In 1954, Mr. Bragg opened his own consulting practice. He is now associated with Documentation, Inc.

Mr. Hincks, Research and Statistical Dept. head, Aerospace Industries Association of America, Inc., is a graduate of Yale University and joined AIA in 1955 after 17 years of service in the Office of Statistical Standards, Federal Budget Bureau. Assignments undertaken by Mr. Hincks during his FBB tenure include establishment of an internal reporting system for the Smaller War Plants Corporation (1945); direction of the Office of Survey Standards, Civilian Production Administration (1946); establishment of the Reports and Forms Control Office of the National Resources Board (1948); and assistance to the Bureau of the Census (1953) in planning the quinquennial census of manufacturers.

Central Management

Criteria for appropriate information are necessary at all levels in order that decentralized decision-making work properly.

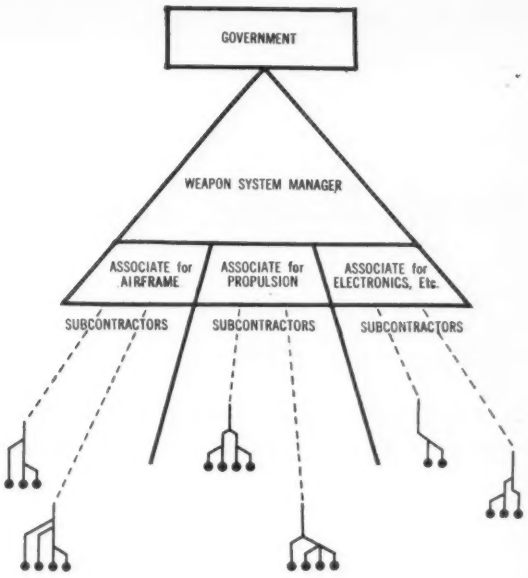


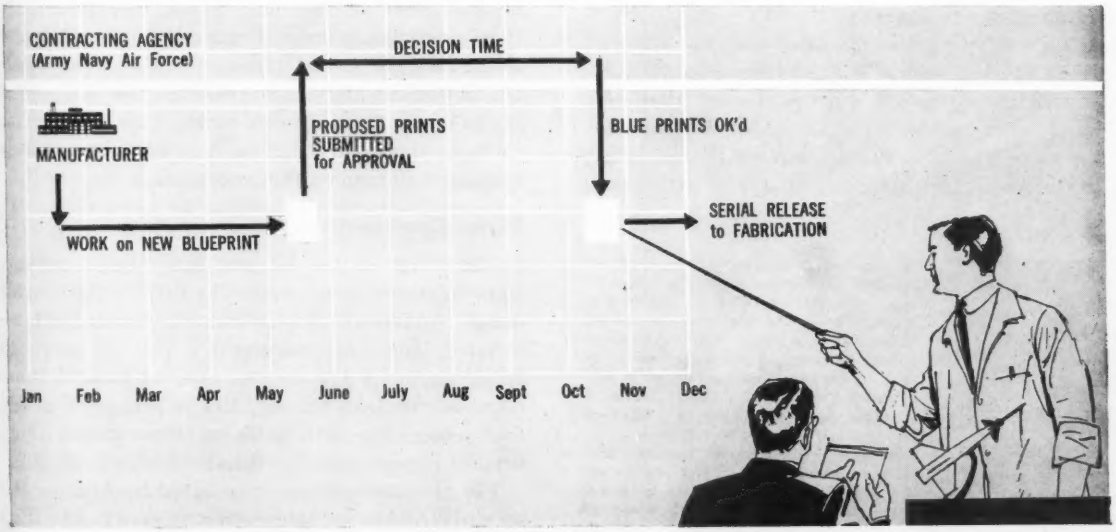
Fig. 1. Decentralized industrial complex.

can illuminate the incentives and criteria for the performance of decision-makers, showing the quality of performance and making it possible to avoid excessive supervision. Such a system displays the division of responsibility among the participants and the relationship, in weapon systems development, of development time, dollar, man-hour and other resource costs, and product performance and reliability. What to observe, measure, record, and transmit—the essence of any information system—can be specified in programs of industrial complexes in the light of an analysis of *networks* and the substance of the decisions displayed there.

Networks

The term *network* is coming into increasing use to describe the relationship of activities and events which comprise the internal structure of the program between its start and termination. *Program* in this sense describes a complex of activities in which one person or organization directs the efforts of others contributing to the accomplishment of a specific development, production, or construction objective. A weapon system team is put together for one specific program. In large weapon system programs, like the above-cited B-70, (*Continued on page 53*)

Fig. 2. Decision time—The static interval in dynamic programs.



Hawk Missile System Electronic Repair Shops

A missile support equipment program to provide a mobile field repair shop with facilities to accommodate all support requirements.

W. J. Perreault, *Radio Corporation of America*

MISSILE SYSTEMS require complicated support equipments for the prelaunch checkout and control phases. The mission of this equipment is to assure the success of every launching. The design of support equipment in general delays the design of the prime system it serves, and in some cases becomes a stepchild in the overall program. The support equipment program, therefore, requires that the design not only matches the requirements of the prime system, but takes into account methods to rapidly and economically accommodate any prime system changes or modifications. For this reason, a thorough Systems Operational Study, equalling that of the prime system, must be conducted for the support equipment, before any design can begin.

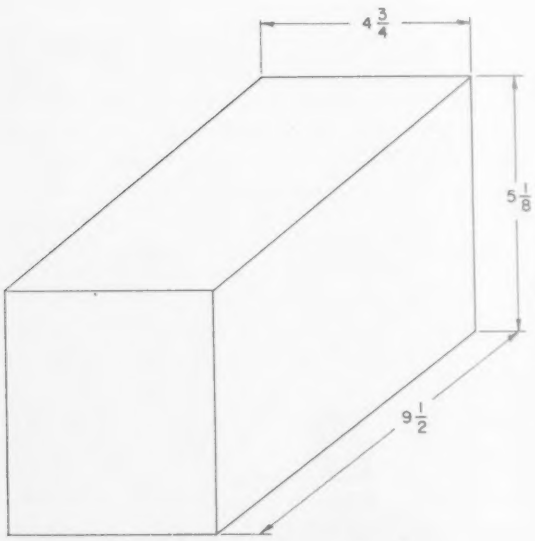


Fig. 1. Basic drawer size.

For the Hawk missile system, this study indicated that the checkout problem should be divided into two distinct phases; (1) the prelaunch, launch, control, and organizational maintenance phase (1st and 2nd echelon field support), and (2) the repair and field maintenance phase (3rd and 4th echelon field support). The first phase employed only those equipments deemed necessary for field operations, and the second phase, all other equipments which would be needed to maintain the operational status of the Hawk Missile units in the field. This solution appeared to make it possible to provide maximum efficiency during each phase.

Design Considerations

The design of the 1st and 2nd echelon support equipment was more or less dictated by the specific detail requirements of the Hawk missile and associated launching equipment. The 3rd and 4th echelon support equipment, however, posed a quite different problem, namely, how to provide a mobile field repair shop with facilities to accommodate all support requirements for the Hawk missile system.

The mobility problem was solved by housing the shop in air-transportable shelters to permit air-lifting

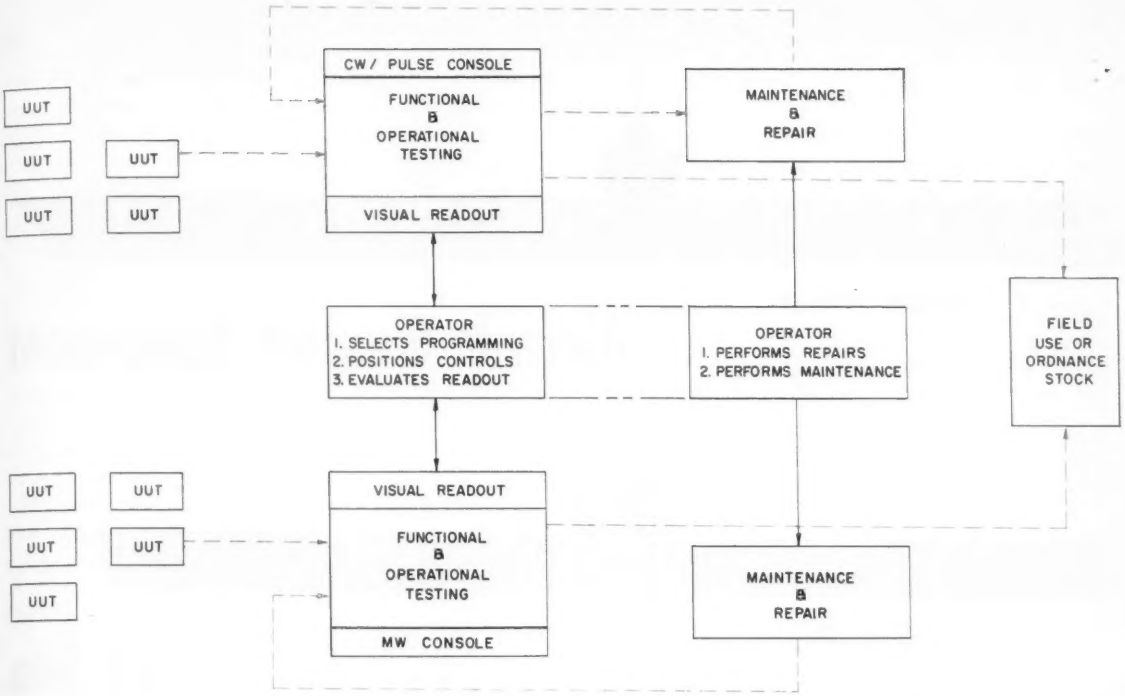


Fig. 2. Unit Under Test (UUT) flow chart.

from one missile site to another. In this manner, a single shop could satisfactorily service several sites, if necessary, or could quickly follow the equipment as sites were changed. The remaining problem was to design a repair shop which would precisely serve the mission of both the missile and its operating personnel.

Feasibility Study

A feasibility study to resolve the electronic aspects of that question was undertaken by RCA that resulted in the following conclusions:

(1) The equipment had to be restricted to use only the 400 cycle power available at the system sites.

(2) The equipment had to contain only those electronic units essential to the successful completion of the mission.

After careful analysis of these criteria, a thorough examination of all available information concerning the units to be tested, and the requirements of the Hawk missile system, a test system was proposed which had the following major features:

(1) Modularized console construction (2 console types only).

(2) Semiautomatic or manual programing of multiple range instruments.

(3) Direct reading, analog type indicators.

(4) A modularized, direct reading counter.

(5) Programable stimulus generators.

(6) Programable power supplies.

(7) Maximum test capability in relatively small space.

(8) Expandable test capabilities.

(9) Self-checking features.

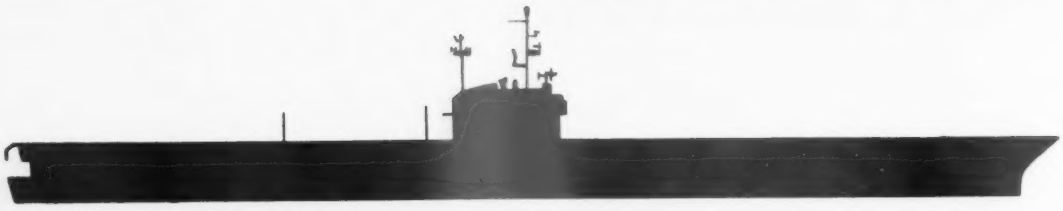
Modularized construction of test equipment was chosen to ease repair and replacement, and because it simplifies the logistic problem. In addition, it provides for the modification of designs and equipment without the usual high rate of obsolescence and cost.

Two console types using only 26 different modules were designed to provide all electronic tests for the Hawk missile system. One console is used primarily for tests which involve microwave units, and the other for tests involving CW and pulse units. However, both consoles provide for tests and checks of common parameters, such as voltage, current, and impedance. Each contains the necessary power supplies for the units to be tested. (*Continued on page 66*)

Mr. Perreault received his B.E.E. from the University of Minnesota in 1958. Prior to that, he had served in the U.S. Navy as a fire control technician where he was responsible for the operation and maintenance of several types of experimental gunfire control systems aboard the U.S.S. "Timmerman." Upon joining RCA he was a specialist in a systems integration group for airborne flight and weapons control. He next designed special purpose solid state circuits for use in advanced equipments. He is presently assigned to Missile Test Equipment projects and is responsible for integration and test. Mr. Perreault is a member of the IRE and the AIEE.

Enterprise

Aircraft Support Equipment at Sea

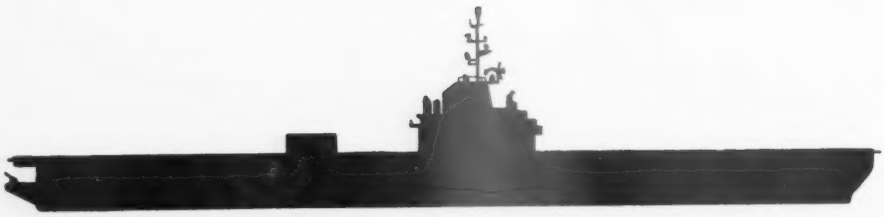


Forrestal

Midway

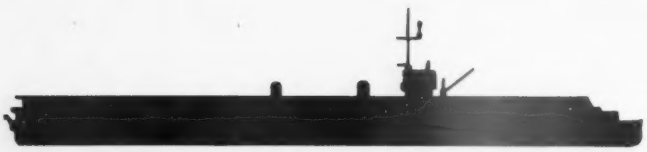
Leonard Lipson and Thomas A. Lyle

Bureau of Naval Weapons, Department of the Navy



Essex

Typical items of support equipment currently being used aboard aircraft carriers, and the criteria to be considered in their design and development.



Langley

Fig. 1. The growth of aircraft carriers during the past 40 years.

While the importance of aircraft support equipment has been widely publicized during the past few years, its value has long been recognized by the Navy as an integral part of the task of maintaining aircraft at sea. From the pioneering flights of the first Navy squadrons aboard the U.S.S. "Langley" to today's supersonic jets, each advance in aircraft or ship design has been matched by similar advances in ground support equipment. These advances have been necessary in order to balance all facets of carrier operations (the man, the ship, the aircraft, and the equipment) into a single harmonious team in order to achieve the full potential of Navy aircraft. It is the intent of this paper to describe typical items of support equipment currently being used aboard aircraft carriers, to discuss the problems imposed by this environment, and to emphasize certain criteria which must be considered in the design and development of support equipment at sea.

The Environment

This fiftieth anniversary of Naval aviation marks a high point in the development of both carrier and aircraft potentials. The following aircraft and ship developments have posed new requirements for support equipment and are presented to serve as an introduction to the environment in which modern carrier support equipment must operate.

The top speed of carrier-based fighter aircraft has increased more than threefold during the past 10 years. Naval aircraft speeds in excess of 1,300 knots are now possible due, in part, to the intensive development of turbojet engines which now deliver sufficient power to challenge the imagination of aircraft designers. The introduction of steam catapults and boundary-layer control systems has improved control of high-speed aircraft during launch and recovery operations, thereby enhancing the safety and reliability characteristics of the aircraft. This has resulted in the utilization of highly sophisticated aircraft equipped with operational systems designed to exploit greatly improved performance characteristics. Unfortunately, this system sophistication has in turn resulted in attendant complex support systems which, heretofore, were limited to land-based aircraft.

Carrier size has grown from the 40,000-ton-displacement of the World War II Essex Class to the 85,000-ton-displacement of the soon-to-be commissioned Enterprise Class. This growth in size, as indicated in Fig. 1, does not relate the full story of the carrier's increased capabilities. Within the hulls of these new ships, the facilities and shops required to maintain the operational readiness of aircraft are, in most cases, equivalent to similar facilities established ashore. It should be noted, however, that while the facilities are equivalent, an intensive effort has been expended to provide equipment which is compact enough to fit the limited working areas available.

The complement of attack-type aircraft loading aboard Enterprise Class carriers has been greatly increased over previously assigned numbers of similar attack aircraft aboard Essex Class carriers. This has been accomplished while maintaining the Essex Class capacity for fighter and early warning aircraft. In spite of the increased size of the ship, the increased number of aircraft to be maintained poses many problems because of the storage and operational restrictions which exist within these complete but necessarily confined maintenance areas.

Within the confines of the carrier it has been possible to provide both the maintenance capabilities of a modern air base and living space for a crew of over 4,000 men as well. While the modern carrier has assumed dimensions considered impossible only 20 years ago, it must be recognized that it is still influenced by the sea environment. Equipment utilized must be capable of operation during normal pitch and roll of the vessel, resistant to the highly corrosive sea water atmosphere, and compact enough to fit into the limited working spaces available.

Criteria

In spite of the vast improvements in the capabilities of carriers and aircraft, the operating environment still taxes the abilities of both men and machines. Equipment must be provided to meet the requirements of the swiftly paced tempo of carrier operations. The following closely related criteria have been selected to discuss guidelines which can be used for the design and (*Continued on page 60*)

Mr. Lipson, Assistant to the Head of the General Support Equipment Section, Bureau of Naval Weapons, is responsible for the design, development, and procurement of standardized aircraft ground support equipment. He received his Bachelor's degree in mechanical engineering from Drexel Institute of Technology in 1955 and is doing graduate work at George Washington University in the field of engineering administration. He has been associated with various aspects of ground support equipment during the past 5 years while employed by the Bureau of Naval Weapons.

Since 1953, Mr. Lyle has been Assistant Head of the Propulsion Support Equipment Section, Ground Support Engineering Branch, Bureau of Naval Weapons, responsible for the design, development, and evaluation of specialized support equipment for propulsion units of Naval aviation. He is a registered Professional Engineer in the District of Columbia, and a member of the National Society of Professional Engineers. Mr. Lyle received his B.S. degree from East Tennessee State College in 1942 and began his Government service the same year. He has done graduate work in engineering administration at George Washington University.

Range Safety—

Adolf H. Knothe
NASA Launch Operations Directorate

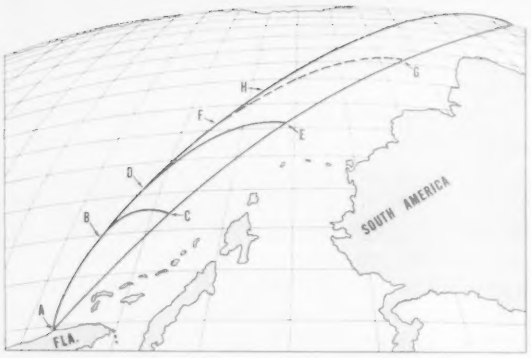


Fig. 1. Trajectory of an arbitrary three-stage vehicle showing both applications—ballistic missile and space vehicle. *A* = launcher; *B* = cutoff, first stage; *C* = impact, first stage; *D* = cutoff, second stage; *E* = impact, second stage; *F* = cutoff, third stage in the case of a ballistic missile; *G* = target of the ballistic missile; *H* = cutoff, third stage in the case of a space vehicle. At point *H* injection is achieved either into an orbit around the earth or into a so-called parking orbit—from which departure onto a space trajectory may be achieved by restarting the third-stage motor(s) at a suitable time; or *H* is the injection point into a space trajectory directly, depending on the velocity achieved at this point.

Dr. Knothe is a member of the Technical and Scientific Staff of NASA's Launch Operations Directorate, Cape Canaveral. In 1952 he obtained his Ph.D. in applied mathematics from Darmstadt Technical University, Germany, after having served there 4 years as a Scientific Assistant. From 1943 to 1945 he conducted stability investigations of guidance and control systems at Peenemuende. He joined the U.S. Army's Guided Missile Development Division (later ABMA) in 1952, working in the fields of inertial guidance systems and trajectories. In July 1960 he transferred to NASA. Presently his main interest lies in range safety problems.

THE RANGE SAFETY PHILOSOPHY presently employed needs modification to accommodate space age requirements. These new requirements, on the other hand, cause concern within agencies which have virtually not been involved in missile launch operations previously. Therefore, the purpose of this paper is twofold: first, to describe, in general, the hazards inherent in missile and space vehicle launch operations and the influence that range safety activities can exert upon these hazards; and second, to present the reasons for, and outline of, a new range safety philosophy.

Range safety activities manifest themselves ultimately in premature flight termination if deviations from the nominal trajectory occur which might cause a threat to human life and/or property. The reason that range safety activities on the other hand are quite unpopular with the developers of missiles or space vehicles is purely technical and economical—valuable technical information can be derived even from a grossly misbehaving vehicle. Considerations of humanity, however, and political implications make it mandatory that a missile or space vehicle, or parts thereof, be prevented from impacting in certain predefined areas. In some applications it will be impossible to provide absolute maximum protection to all land masses without seriously jeopardizing the mission, or even making it impossible.

The term "vehicle" will be used in this paper to designate both ballistic missiles and all kinds of spacecraft. The stages of a space vehicle, with the possible exception of the last stage, are, as far as the range safety problem is concerned, not different from the stages of a ballistic missile. Also the orbiting or escaping stage of a spacecraft poses a range safety problem in case of malfunction—that is, in case an orbit or escape trajectory is not achieved. The return of a spacecraft from an orbit or from a space flight mission must be considered, too.

Risks Involved in Missile and Space Flight Operation

This article considers threats to life and property only on the surface of the earth. At the present time, there is no indication that some kind of protection might be necessary for certain areas on the surface of other planets. First, only the risks caused by missile and spacecraft launchings will be discussed without regard to possible range safety activities. If a vehicle would perform as planned, any particular range safety problem could be avoided. The stages of the vehicle would impact in preselected areas and the last stage would reach its target, which might be a certain area on the surface of the earth (ballistic missile flight or return from a space mission), an orbit around the earth, a point on the surface of another celestial body, or an orbit around

A Necessary Evil

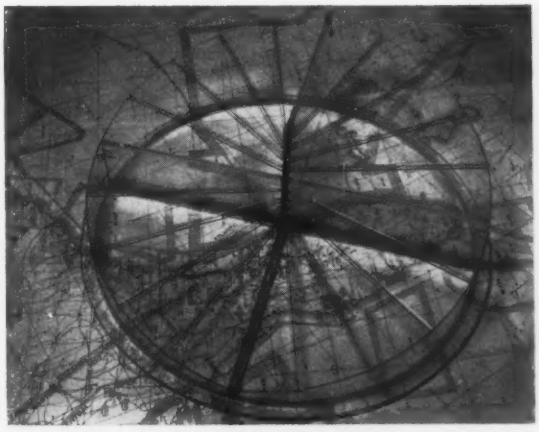
Space vehicle launch operations make necessary modernization of the presently employed range safety philosophy. A new philosophy is thus here presented.

another celestial body. In summary, therefore, two different types of target are of interest to an earth-bound observer: a point on the surface of the earth or a point in space, at which injection occurs into orbit, parking orbit, or space trajectory (Fig. 1). Consequently, the threats to be considered here stem only from malfunctioning vehicles. All kinds of malfunction create such threats. For instance, propulsion may stop prematurely, or the propulsion of an upper stage may fail to start. The threat from such malfunctions would manifest itself in possible impacts on, or in the neighborhood of, a line in flight direction, the so-called locus of *i*nstantaneous *i*mpact *p*oints. This is a line (often referred to as the "IIP line") connecting points on the surface of the earth which would be impact points of an otherwise perfectly normal vehicle if its propulsion were terminated prematurely at any arbitrary time (Fig. 1).

Other malfunctions which influence the vehicle attitude, and consequently the orientation of its velocity vector, can cause deviations from this IIP line to various degrees. Possible impact points for a conventional ballistic missile are confined to a roughly circular area around the launcher with a radius equal to the maximum range this vehicle is capable of achieving. The impact probability density, however, will vary considerably over this area. It can be expected that in any case it will be largest along the IIP line and it will decrease in some fashion with azimuth deviation from the IIP line (Fig. 2). But it may vary also in radial direction. The impact probability density for a malfunctioning one-stage vehicle, for example, will decrease about quadratically with the distance from the launcher if the probability of accidental thrust termination is considered independent of burning time.

For multistage vehicles, of course, a radial cross section through (*Continued on page 70*)

Fig. 2. Simplified model for the impact probability density distribution of a malfunctioning arbitrary ballistic missile, launched from Cape Canaveral. Here it is assumed that the impact probability density depends only on, and decreases linearly with, the azimuth deviation from the nominal flight line. The target, and the possible scatter around it, of a nominally performing missile are not shown. It may be imagined that the target lies anywhere on the nominal flight line at a distance from the launcher equal to or greater than a given value representing the minimum operational range of the missile concerned, and shorter than the radius of the model shown. The radius of the model represents the maximum range the missile is capable of achieving under any circumstances.



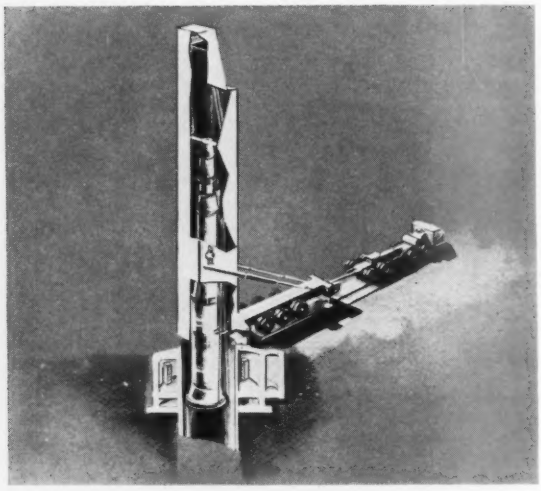


Fig. 1. Missile emplacement with transporter-erector.

Minuteman

George T. Drakeley, AFIAS
The Boeing Company

AT THE START of the Minuteman program, an extensive transportation study was made to determine the most practical and economical means of delivering the missile to the launch site and emplacing it in the silo. The results of this study dictated an essentially self-contained, over-the-road vehicle. Known as the transporter-erector, this vehicle became the basic item of transportation and handling equipment in the Minuteman system and greatly influenced the design of the rest of the equipment.

Highway Design Criteria

Included in the study was a survey of existing highways and bridges, as well as legal restrictions and permit limitations on highway travel in the Midwestern states. The total payload to be carried (approximately 73,000 lbs), which includes the missile without re-entry vehicle, engine harnesses, base adapter ring, and miscellaneous hoisting components, approximates the legal highway gross weight limitations in most states. Since the loaded vehicle then would exceed all state legal gross weight limitations, criteria to permit movement over an adequate percentage of highways and bridges by special permit were established to serve as bases for design. These highway criteria are as follows:

(1) Maximum total gross weight, 108,000 lbs.

(2) Maximum axle loading, 18,000 lbs.

(3) Axle group loading and spacing to meet the California Highway Department purple curve.

(4) Minimum spacing between tractor axle group and trailer axle group, 30 ft.

(5) Turning capability to permit negotiating a 90-deg intersection of two 32-ft wide roads.

(6) Normal height not to exceed 13 ft 6 in. with the capability of achieving a roadable height not to exceed 12 ft 6 in. under controlled speed and road roughness conditions.

(7) Articulation clearance between the tractor and container adequate to permit approaching a 17 percent ramp.

(8) Overall width not to exceed 10 ft.

Transporter-Erector Design

In addition to these highway criteria, additional criteria were established:

(1) Structural stiffness to prevent overloading the missile as a result of deflection.

(2) Environmental control to maintain a missile temperature of 80° with design ambients of minus 35° to plus 115°.

(3) Integral emplacement system.

(4) Emplacement capability under wind conditions of 45 mph.

Container stiffness and spring constants for tires, tractor, and trailer suspension and harness suspensions were computed to obtain a system related to missile stiffness to prevent overload of the missile engines and interstage structure.

Mr. Drakeley has been Chief of the Base and Mechanical Ground Support Equipment Design Section for the Minuteman Project at Boeing since activation of the program in the fall of 1958. He received a B.S. degree in mechanical engineering at Oregon State College in 1939. Since 1941, he has been associated with Boeing in the design of landing gears, mechanical controls, and jet thrust reversers. Mr. Drakeley spent 7 years in the Preliminary Design Dept. and later headed the design group for the Supersonic Wind Tunnel.

Missile Transportation System

▸How can the missile be delivered to the launch site?

▸How can it be placed into a silo?

The transporter-erector provides an economical answer to both questions.

In order to meet the 108,000-lb gross weight limitation, a weight budget was established for each of the major components—tractor, rear carriage, container, and emplacement system. Close design control and, to some extent, departure from normal design approaches for this type of equipment were necessary to meet the weights.

Fig. 1 shows the use of the transporter-erector for placing a missile in a silo. The rear carriage is tied down at the site and the container erected. This carriage forms a stable platform. The container pivots about a hinge and erects to approximately 89 deg from the horizontal. The hoist system then travels approximately 15 in., moving the missile away from its harnesses. In this free position the missile is supported as a pendulum by hoist rods from the base adapter ring. The missile is stabilized at the top by a ring connecting to the hoist rods. From this suspended position, the missile is lowered into the silo.

The low profile of the tractor and its relationship to the container is shown in Fig. 2. The hoist is housed in the forward end of the container. Hoist rods can be seen through the cutaway mockup. Power take-offs on the tractor transmission are used to drive hydraulic pumps providing power for the emplacement system.

The container environmental conditioning system utilizes heat rejected by the engine as the heat source to maintain missile temperature.

The transporter-erector is currently undergoing qualification tests. Fig. 3 shows an erected container during life cycle tests. Qualification testing will also include rough road tests, railroad piggyback operation, environmental control, and missile handling and emplacement. (*Continued on page 78*)

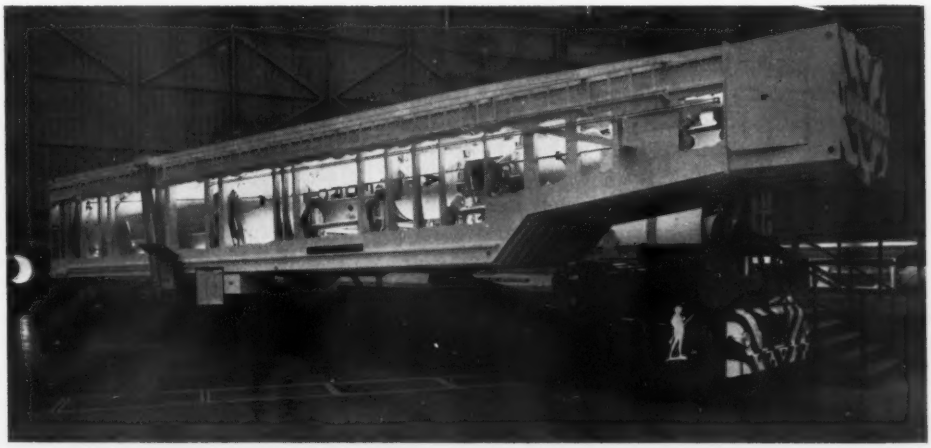


Fig. 2. Cutaway mockup of the transporter - erector container with prototype tractor and rear carriage.

SPACE AND DEMOCRACY

Richard S. Morse, *Department of the Army*

I FEEL very much like the commencement speaker for a high school graduation exercise. On such an occasion, the speaker is expected to deal with the future and its opportunities in glowing terms, indicate and minimize the obstacles that will surely be encountered, and issue a stirring challenge for the future.

The Aerospace Industry has, in my opinion, reached that critical stage comparable to graduating from high school. Insofar as Space is concerned, the industry isn't even that far along. The Aerospace Industry does not have a single commercial space product or service on the market. Therefore, if we are to develop fully the potential of this "teenager," we must determine a sound program for the future in accordance with the best business and management policies.

Growth of Aerospace

For all practical purposes, I consider that the Aerospace Industry suddenly became an adolescent on October 4, 1957 when Sputnik I was launched by the Soviets. Since that time, we have witnessed phenomenal growth in our space requirements and capabilities. A recent unofficial estimate puts the aerospace market for fiscal 1962 at a fantastic $17.9 billion. Almost $5 billion of this total is for aerospace research and development programs in the Department of Defense and NASA, of which $2 billion will be spent for research and development in space programs. Within a short span of 5 years we have witnessed the growth of this infant into a sprawling uncoordinated teenager still subject to growing pains, and not fully aware of what lies ahead.

Growth of the Aerospace Industry has been tremendous. Based on the record to date, many people have predicted the trend will continue and that in the not-too-distant future a space industry will occupy the same national prominence that the automobile industry has today. I think it is unrealistic and wishful thinking to believe that a new space industry will reach 10 percent of our Gross National Product (GNP) or about $50 billion in the near future. Our total defense budget, which includes thousands of items in addition to missiles and space projects, is only about $43 billion. The space business to date has been essentially all research and development in the sense that reliable operational systems are few and far between. A very large portion, as high as 30 to 50 percent, of our major space programs involve research and development as compared to hardware procurement. Research and development, while essential, is only a means to an end for something useful. And something commercially useful must be developed for space if the industry is to prosper and grow. There is an end in sight to the missiles and planes that are needed for our deterrent capability.

Era of Exploding Technology

As we move ahead in this era of exploding technology, research and development is our manifest destiny. The impact wrought by this young giant knows no boundaries, and deals harshly with those who linger along the wayside. No segment of our daily life is now immune to the influence of science and its products.

National policies of retaliation and deterrence resulted from consideration of future research and development capabilities. The first nation to develop successfully an effective defense against the intercontinental ballistic missile will, for a time, enjoy a definite strategic and political advantage. We know that the USSR recognizes the advantages and need of such a capability and now has a large active program to develop an anti-ICBM defense

The IAS-Army Aviation Meeting address presented here, while given well after the deadline for this Aerospace Support Issue, revealed itself as an unusual target of opportunity. Virtually unedited, it is published because of the obvious applications to our theme, as well as to the industry as a whole. It is recommended reading for those who can benefit from some serious thinking by a top Government official with extensive technical and business experience. • EDITOR

Mr. Morse was appointed Assistant Secretary of the Army for Research and Development last March 3 after almost 2 years as Army Director of Research and Development. In his new position, he will have increased authority and broader responsibilities, including procurement for R&D purposes. Associated for many years with the Nation's defense effort, he is recognized as a pioneer in the field of high-vacuum technology and as a technical executive with extensive experience in organization and management of business ventures. He has been President of Columbia National Corp., NRC Equipment Corp., Minute Maid Corp., Vaculite Corp., and Vacuum Metals Corp., as well as having held directorships in New Enterprises, Inc., and Escambia Chemical Corp. He received the Distinguished Civilian Service Award this year.

system. So today, and we can expect this to be more so in the future, national security policy is influenced by research and development. Never before has the country had such a need for close coordination of our national security policy with present and future military posture based on a careful appraisal of our relative positions in a rapidly changing world of technology.

Within the Department of Defense, future space roles and missions of the individual Services are being determined, directly or indirectly, by the assignment of new research and development programs. A change in role or mission of a service after a new weapon system and concept has gone through the R&D phase is costly in time and money, hence is not likely to occur. The directive recently issued by the Secretary of Defense, assigning development responsibilities for projects in space, illustrates the impact of R&D upon the roles and mission of the services for the future and emphasizes the need for early effective decisions in this expanding and costly area of activity.

All three services in the Department of Defense recognize the growing importance of research and development and each now have an Assistant Secretary for Research and Development. Both the U. S. Army and the U. S. Air Force have recently (April 1961) taken steps to increase the effectiveness of their R&D organization. The authority for the Army Assistant Secretary for Research and Development is, under a recent Army general order, clearly separated from logistics; and he now has responsibility in the R&D field for procurement, research, development, test and evaluation. Each service ultimately needs a centralized R&D structure in which research and development is organized by technical areas, and in which a single authority has responsibility for the development and initial procurement of our more complicated systems and advanced research projects. Such a management structure would be welcomed by industry, particularly as the developing firm would normally be awarded contracts for initial production.

Talents and Instrumentation

The scientist and the engineer have been instrumental in bringing about this era of exploding technology, and as the pace increases they face challenges beyond the boundaries of science and engineering. Their greatest obligation to the country is to be objective at all times. They must not advance parochial views based upon inadequate research or selfish motives. Our scientists and engineers must make their talent available to our country whenever and wherever needed. The fact that a man is a scientist or engineer by training or reputation does not necessarily mean that he is also competent to manage and divert programs. This country, as never before, needs technical management talent—talent that is also willing and eager to work in cooperation with our talented and dedicated military people. They are (*Continued on page 79*)

Application of Operations Research for Site Planning Facilities Support

Phillip J. Daniel

Daniel, Mann, Johnson, & Mendenhall

THE APPLICATION of mathematical techniques to planning gives a means of analyzing planning and preproving architectural and engineering design concepts. The word *concepts* is important in this context because it implies a wide variety of choices available to designers. The mathematical techniques employ methods of straightforward linear mathematics, some algebra, calculus, and other associated operations research techniques.

Historically, the traditional method of developing concepts for large-scale facilities, master plans, site plans, large industrial works, or military-complex installations has generally employed the following approach consisting of four basic steps:

(1) Conscientious gathering of criteria requirements for the project by an individual or group of individuals—experienced or otherwise.

(2) Consideration of limiting factors on the control of concept designs, such as land areas, cost limitations, time elements, etc.

(3) Study of the criteria and factors by a senior, experienced planner, who develops a "conceptual feeling" for the project, eventually leading him to the drawing board and the rough-sketch period.

(4) Development by a senior designer, along with others, of 30, 50, or perhaps hundreds of sketches on flimsy paper until he intuitively recognizes one or more of the concepts to be sufficiently good to warrant concentrated additional development for final designs. At no time is there a formal testing of the validity of designs.

This is the common process used today. It has been used for the last 2,000 years! Results are normally quite satisfactory, depending on the talents and training of the designer-planner. However, much time and money are wasted producing unusable and unsatisfactory "cut and try" designs while searching for practical solutions. More significant, however, there is no proof of "what was done" or "why it was done," or what finally determined the so-called "good solution" by the designer. Such verification is not available because the bulk of the original working sketches previously developed were thrown into the waste basket and destroyed as the approach to the final design proceeded. Indeed, if these were saved, they would still provide no proof!

This lack of proof is not only unfortunate, but dangerous; therefore, this paper presents a method of making use of suitable mathematical techniques to pre-analyze and pre-evaluate the various factors important to design solutions, and to analyze and record these evaluations *before* preliminary design layouts are commenced. The process often involves the "weighting" of selected factors in accordance with their importance. This is followed by using these factors in one or more series of equations or formulas which, when solved, will assist in the early elimination of obviously unacceptable schemes if results so indicate. Of utmost importance, it gives a retainable record of why and how the designs and solutions used were arrived at and found to be acceptable. It thus provides evidence and proof of the reasoning which led to the final solution.

The author gratefully acknowledges the valuable assistance of Ralph W. Allen, MIAS, Senior Operations Research Scientist and Assistant Head, Space Systems Branch, of the System Development Corp., Santa Monica, Calif., on certain mathematical approaches and choices evident here. Mr. Daniel and Mr. Allen have worked together on other operations research efforts, including the education field.—*Ed.*

"A method of making use of suitable mathematical techniques to pre-analyze and pre-evaluate the various factors important to design solutions, and to analyze and record these evaluations before preliminary design layouts are commenced."

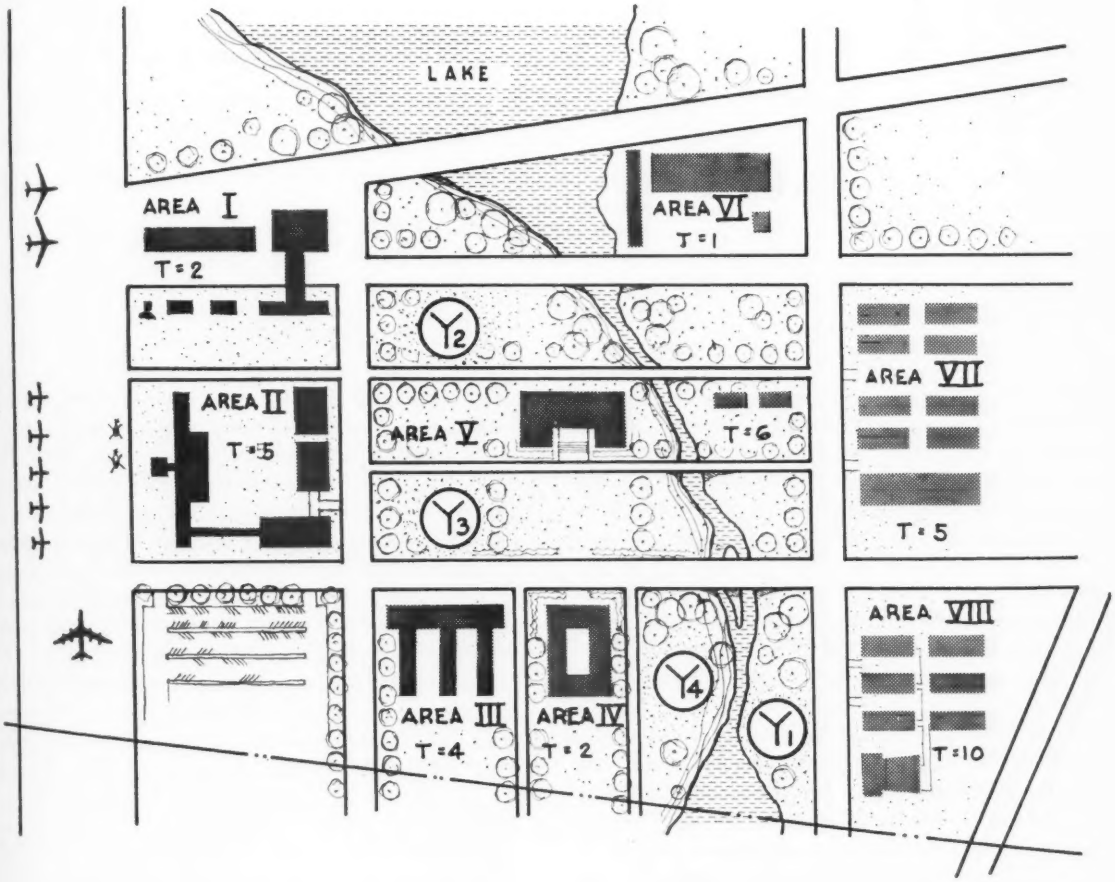


Chart A. Eight areas (I–VIII) must be served; four possible locations (Y1, Y2, Y3, Y4) for new facility; T = weighting factor (1–10) based on number of people or rooms per area (by count or estimate).

Problem Approach

In subjecting physical site/master planning to analysis and scrutiny by mathematical techniques, the whole planning problem is first broken down into six identifiable types of individual problems which (a) are generally common to all site or master planning, (b) can *reasonably* be aided by these mathematical techniques, and (c) are problems to which these mathematical (*Continued on page 81*)

Mr. Daniel is Executive Vice-President of DMJM, Architects & Engineers. He started the firm in 1945 after serving as Radar Officer in the U.S. Navy, and his personal interest in research and development and advance planning has been the prime mover in its expansion and diversification into the space and systems engineering fields. Mr. Daniel received his Bachelor of Architecture degree from the University of Southern California. His 20 years of experience in planning, design, and engineering have been recognized by the National Council of Architectural Registration Boards, and he holds professional licenses as architect in California, Nevada, Kansas, Hawaii, and Japan.

W. C. Stormer

McDonnell Aircraft Corporation

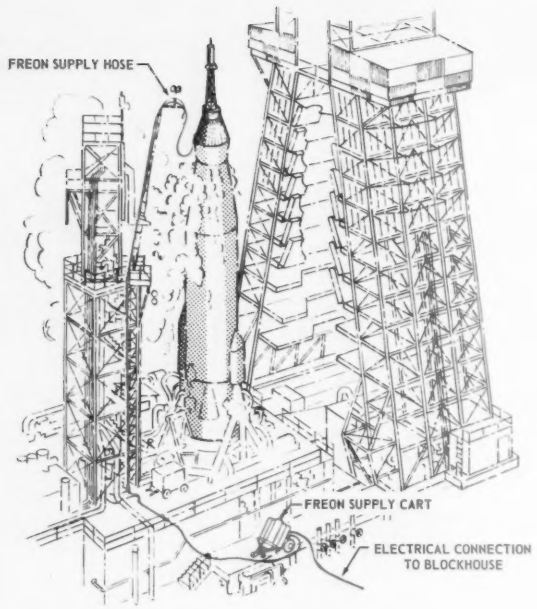


Fig. 1. Launch site installation.

FREON 114 is used as a refrigerant in the Mercury Capsule prelaunch environmental control system support equipment. Under the strong solvent action of Freon 114, it was found that the rubber-lined hoses conforming to MIL-H-5593 used in the tubing system of the support equipment released oil and contamination which were dissolved into the Freon. During functional checkout of the support equipment, contamination of the Freon caused clogging of a filter and contaminated relief valves and regulators until the system became erratic in operation.

Prior to launch, and during countdown when the capsule is on the booster and the astronaut is in position with the hatch sealed, the capsule air-conditioning system will be inoperative (Fig. 1). During this period, ground-support equipment will be in operation furnishing the necessary cooling to the capsule environmental system and the astronaut's suit circuit. This equipment consists of several bottles of Freon 114, a nitrogen bottle, pressure regulators, relief valves, gages and the necessary electrically controlled valves for remote control operation. Freon 114 is forced into the capsule environmental system evaporator through the capsule umbilical connection at rates up to 110 lb/hr, as demanded. The desired degree of cooling is attained at the direction of the astronaut via intercom to the ground crew in the blockhouse who make the necessary adjustments to the ground-support equipment. Immediately prior to launch, the Freon flow will be cut off by controls in the blockhouse and the Freon line separates from the capsule as part of the umbilical assembly. Contamination of the capsule environmental system evaporator or malfunction of the support equipment could seriously affect the entire launch operation at a critical time. Therefore, it is of utmost importance that pure Freon with no additives be used and that the support equipment be free of any contaminate.

Tests were performed to determine the compatibility of Freon 114 with various hose materials. Following is a résumé of the hoses investigated and those tested and the results and conclusions of the investigations.

Buna Compound Hose

Sample 1

Using a 10-ft. length of hose as a test specimen (Fig. 2), Freon was left to stand in the hose under 125 psi pressure for 24 hours. At the end of this period, the Freon was drained into a beaker. After the Freon had evaporated, a measurable amount of oil and considerable contaminate remained in the beaker. Since all rubber compound hoses are manufactured with varying amounts of oil in the compound and since the Freon tends to remove this oil and distribute it throughout the capsule system, it was determined that any rubber compound hose would produce similar results.

Sample 2

Another buna compound hose was tested. This was a hose recommended by the manufacturer as suitable for a closed cooling system using Freon 12

Compatibility of Freon 114 Used in Mercury Support Equipment With Various Hose Materials

Capsule environmental system evaporator contamination or support equipment malfunction could seriously affect launch operations at a critical time; thus the need for pure, uncontaminated Freon.

as a cooling medium since it had a much smaller percentage of oil compound in its physical make up. This hose was tested for compatibility with Freon 114 under conditions similar to those to which it would be exposed as part of the prelaunch environmental control system. The results of this test showed that a smaller amount of oil was extracted from this hose than from Sample 1. Again, a 10-ft length of hose filled with Freon 114 was left to stand for 24 hours. At the end of this period the Freon was drained into a beaker. After the Freon had evaporated, an oily film and a small amount of contamination was left in the beaker. This small amount of oil and contaminate was considered to be more than could be tolerated in the ground support equipment.

Compar Hose

The compar hose is physically a polyvinyl alcohol resin compound. Upon investigation it was found that this hose had excellent characteristics with regard to its usage with Freon; however, this hose is water soluble. Since it could not be guaranteed that it would never come in contact with water, it was felt that it should not be used for this application.

Mr. Stormer is Assistant Manager of Support Engineering at the McDonnell Aircraft Corporation. His engineering work has included support equipment design on the F3H Demon, F101 Voodoo, F4H Phantom II and he is currently working on the Mercury Project. After receiving a B.S. degree in Aeronautical Engineering, he took a position with North American Aviation and later with Curtiss Wright before joining McDonnell. His engineering experience has covered hydraulics, pneumatics, power plant and fuel system installations. While at McDonnell, he has been in charge of power plant and fuel systems installation on the F2H Banshee, F3H Demon and later the F4H Phantom II.

Flexible Metal Hose

Convoluted Stainless Steel Hose

Flexible metal hose was found to have excellent characteristics with regard to its usage with Freon 114. However, previous experience with this type of hose has shown that once it has become contaminated, it is very difficult to clean because of the tendency for contaminate to collect between the convolutions. It was decided that guarantee of absolute cleanliness was practically impossible for this type of hose.

Teflon-Lined Hose

A 10-ft length of Teflon-lined* hose was subjected to Freon 114 under 125 psi pressure for 24 hours. This hose was found to possess excellent characteristics in that the Freon did not become contaminated in any way. However, the Freon was permeable in the Teflon hoses (Fig. 3). Tests showed that the permeability rate of Freon 114 in the sample tested was about 0.25 cc/hr at the operating pressure of the prelaunch cooling system. This permeability rate was felt to be so slight (*Continued on page 84*)

*Du Pont trade name for tetrafluoroethylene.

Support of Fire Control Reliability by Automatic In-Flight Evaluation

Stuart T. Belden

Arma Division, American Bosch Arma Corporation

TOP OPERATING PERFORMANCE of the fire control system carried on the B-52 intercontinental bomber is now assured with the installation of attack-simulating evaluators.

Simulation generally implies the synthetic duplication of operating conditions at a ground installation. In the instance of evaluation equipment developed for the U.S. Air Force by the Arma Division, American Bosch Arma Corporation, simulation means the duplication of enemy aircraft attacks in the form of phantom targets, with these attacks taking place at altitude under the same conditions as those imposed by combat. Specifically tailored to the near-space environment of the B-52, the techniques used are equally applicable to the conditions of outer space.

The evaluators impose on the system, or operator, problems of attack more realistic than can be duplicated by the usual practice planes. They permit actual gunfiring against the phantom attackers and record the actions of both man and machine for later analysis and correction on the ground. When applied to problems of outer space, the actions would be ground recorded by a suitable data link.

Such evaluation equipment provides a precise yet simple means for assessing the peak operating performance of the B-52's tail defense system, as well as the proficiency level of the operator of the system. Because restrictions of space within the vehicle preclude carrying along an observer, all actions taken by the gunner and the reactions of the system in defense of the aircraft are recorded on a time base so that effectual analysis may be made.

This equipment, fully accepted for operational use and being manufactured in quantity, has significantly reduced Air Force training and maintenance costs. Heavy expenditures for fighter aircraft, tow targets and drones for training purposes can now be eliminated. On any normal flight, the B-52 gunner may subject himself or his armament system to the rigors of a series of attacks fully representative of any patterns that might be inflicted by the enemy. Of further importance in promoting economy, the evaluation equipment serves to check out the fire control system under actual operating conditions in a matter of seconds, while a corresponding ground test would consume 20 hours with questionable results. It is likewise quite evident that this type of training may be conducted without endangering the safety of the crew, or airplane.

At the desire of the Air Force, the evaluation equipment has been made in two separate packages for alternative use on any one aircraft. One unit encompasses the components for system evaluation, the other for evaluation of the gunner (Fig. 1). A combined unit is feasible with practically no sacrifice in weight or volume since the majority of the components are common to both designs. Each type is comprised of a selector switch located within reach of the gunner and a remote unit consisting of a programer (Fig. 2), a recorder and a group of special-purpose amplifiers.

Trackshot Technique Used

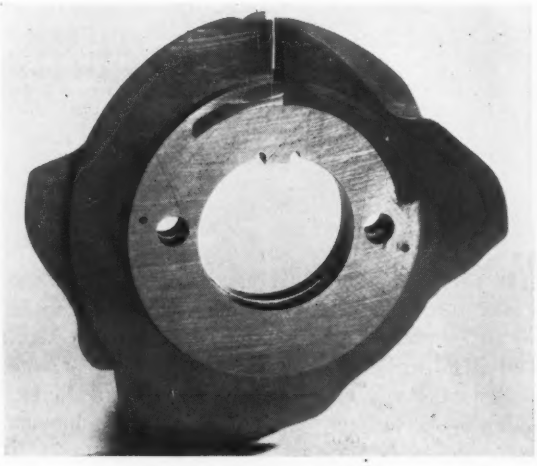
The system evaluator determines the ability of the fire control system to follow a moving point in space, to fire against this point and to hit it with lethal accuracy. The function is accomplished by programing prescribed target attack courses into the fire control system, thereby causing the system's computer to establish the proper lead angle, and then closing the firing circuit at the proper instant. As the projectiles are fired, the radar system tracks the

"Potential applications of this evaluation equipment extend to any radar-controlled, gunlaying fire control system. The techniques are also applicable to shipboard and land-based heavy gun systems."

projectiles into space. At the predetermined point in space where the boresight measurement is to be made, the radar echo signal from the projectiles is recorded as they pass through a fixed range gate. The whole operation is automatic. Since the track antenna boresight line should coincide with the gun line of sight at the end of the projectile time of flight, the radar error signal becomes a measure of the boresight error. Ground maintenance crews utilize these data to reduce the error to zero by recalibrating and harmonizing in accordance with the now established error.

An associated unit (Fig. 3), which may be optionally installed with the evaluator, accepts the voltage representing boresight error and transmits a bias to the track antenna system to offset the antenna in a direction and angle to reduce the error to zero. This operation, known as automatic aerial harmonization, provides quick overall error compensation. However, analysis of the recording will show if any portion of the system is a major contributor to the error and, therefore, requires special maintenance attention.

The operator evaluator checks out the gunner's level of skill in using the full capabilities of the fire control system against an attacking aircraft. The function is accomplished by programing the coordinates of actual attacks into the fire control system so that signals appear in a completely realistic manner on the radar indicator. These signals, as blips of light, move across the indicator screen in the flight pattern of the attacking fighter. The gunner acquires, locks onto and fires against this phantom target as he would in actual combat. His numerous actions in operating the system are recorded as they



Two adjacent helical cams.

take place. Simultaneously, since the target courses are pre-established and the action that should be taken by the gunner at any instant is known, the correct gunner actions are also recorded. This permits assessment of his operating skill by direct comparison between the required and actual gunner responses.

Evaluation by Basic Modes

From a functional viewpoint, the operation is separated into the three basic modes of search, acquisition, and track. In (*Continued on page 92*)

A licensed professional engineer in New York State, Mr. Belden was graduated from Rensselaer Polytechnic Institute with an E.E. degree. As head of Airborne Projects, he supervised the development of airborne evaluation equipment reported in this paper. Most of his engineering career has been associated with military servosystems, especially in the fire control field. In World War II, Mr. Belden designed several types of electric drives for aircraft gun turrets and computing sight control systems. At Arma, he has been a project manager on the B-52 fire control system, shipboard gun mounts and directors, high-speed fuze setting systems, advanced heavy weapons systems, high-intensity searchlights, and associated support equipment.

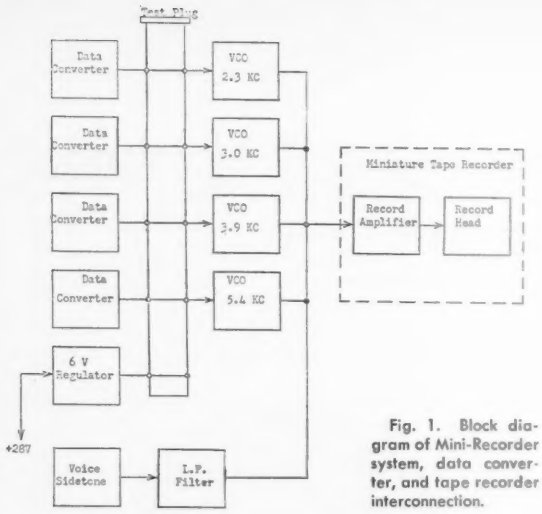


Fig. 1. Block diagram of Mini-Recorder system, data converter, and tape recorder interconnection.

J. B. Renfro
U.S. Naval Missile Center
(Point Mugu)

Mr. Renfro, an Electronic Development Technician at the U.S. Naval Missile Center, Point Mugu, Calif., began his electrical career in 1942 after completing a Navy service school course of training at the Texas A&M College. During the past 10 years Mr. Renfro has been associated with the system design and coordination of the Navy's instrumentation installations in the Sparrow I and III missiles and aircraft systems at Point Mugu. His current position is with the Instrumentation Research Division, Aero-Space Operations Department, where he serves as the cognizant instrumentation engineer over the F3H and F4H aircraft and Sparrow III missile instrumentation systems.

MINI-RECORDER is an expression coined to describe a miniature tape-recorder system which was adapted for airborne use as a flight-test data-gathering device. The Mini-Recorder system was devised at the United States Naval Missile Center, Point Mugu, Calif., for a particular application where equipment mounting space and installation time were at a premium; however, the system is adaptable to most instrumentation problems where an in-flight recording system is applicable, and where the environment and data frequency requirements are compatible with the system.

Flight-test problems occasionally arise when it is necessary to instrument an aircraft system in a minimum length of time, and when available space for instrumentation equipment is practically nonexistent. These problems are particularly pressing with modern jet fighter-type aircraft, where it appears to the flight-test specialist that the concept of aircraft design is to wrap an airframe around the engine, fuel tanks, and electronic equipment, then dig out a hole for the pilot and the radar operator. Creation of an instrumentation equipment mounting space thus practically entails the time-consuming job of rebuilding the aircraft.

The particular problem which led to the development of the Mini-Recorder system was the difficulty of locating instrumentation mounting space and the time available to create equipment space in the F4H-1 aircraft assigned to the United States Naval Missile Center for the purpose of evaluating its missile weapon system. In the F4H-1 aircraft, without extensive modification (including removal of one of the fuel tanks), there is no available space for a conventional airborne recording system, and the routing of necessary wiring is difficult and time consuming.

The greatest difficulty in evaluating two complex and interdependent systems (the aircraft and missile systems) arises when there is an electrical failure in one of these systems—the difficulty of determining whether the failure occurred in the missile or in the aircraft fire-control system. Since it is not always possible to instrument all components of each missile, and since the evaluation program is concerned primarily with the aircraft rather than with a proved missile system, the following information on the aircraft missile fire-control system is needed: (1) aircraft position relative to the target, (2) whether and when the aircraft radar has locked onto the target, and (3) whether all necessary launch-sequence signals are generated and sent to the missile. This information is recorded in the F4H-1 aircraft through photography and the Mini-Recorder system. A camera on the front canopy records the pilot's instrument panel presentation of air speed, altitude, and gyro horizon, when light conditions permit. Also, a

The Mini-Recorder System

"The Mini-Recorder system was designed to have structural and electrical characteristics that would permit its installation near the data points to be monitored and would make it accessible to the aircraft's radar operator. . . Additional aircraft power provisions were not required."

photographic system is used to record the radar operator's scope display. Data required but not available through photography are the aircraft firing-circuit information, range to target, closing velocity (*Vc*), and recordings of the pilot's voice annotations and of intercommunications between the pilot and the radar operator. Prior to the adaptation of the Mini-Recorder system, other systems of recording data were considered. The firing-circuit information, consisting of 28-volt d.c. power functions, could have been monitored by the use of low-current meter fuses, but this would have required the continual checking and replacing of blown fuses. Ground recording of the voice communications was ruled out as a prime data-gathering source since it would have entailed unnecessary congestion of the radio channel. It was therefore necessary to record this information in the aircraft.

The pilot's instrument panel contains a bundle of information on engine performance and flight status, and is being photographed. During aircraft flight evaluation, however, much of the information thus obtained is superfluous to the information desired. The installation of additional meters on the instrument panel for monitoring *Vc* and range data was considered but was not found acceptable because of uncontrollable lighting conditions and the fact that little instrument panel space was available. In view of these inadequate methods of monitoring desirable information, the Mini-Recorder system was designed to have structural and electrical characteristics that would permit its installation near the data points to be monitored and would make it accessible to the aircraft's radar operator. The system was also designed to require such a low drain on the aircraft 28-volt power system (75 milliamp) that additional aircraft power provisions were not required. The information presently recorded by the Mini-Recorder is range, *Vc*, firing-circuit (*Continued on page 85*)

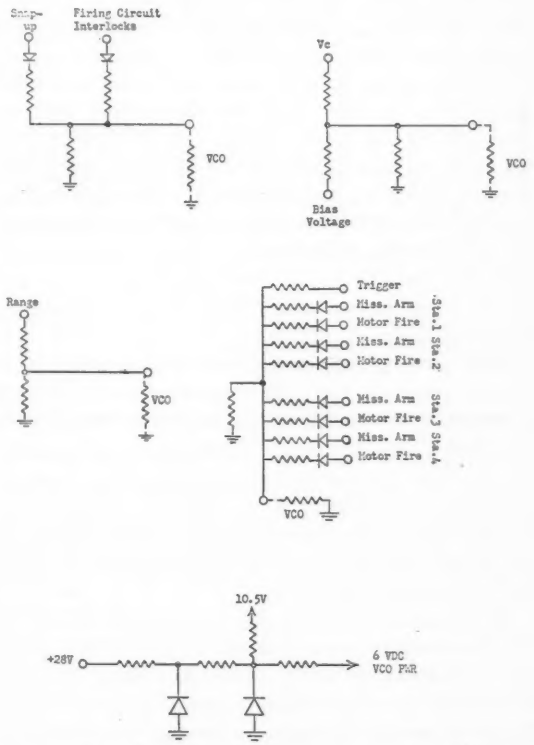


Fig. 2. Individual data converter circuit diagrams and power voltage regulator circuitry.

Corrosion Problems Encountered in Silo Storage of Missiles

Leo E. Gatzek, *Aerospace Corporation*

STORAGE OF combat-ready missiles in concealed, hardened underground emplacements is a strategic concept for implementing the America-NATO defense posture based on the United States policy of deterrence and retaliation. This means, simply, the capability of striking back effectively after an enemy attack. Any weapons system, therefore, must be protected from external destruction. There are three basic ways of accomplishing this objective—hardening, dispersion, and mobility. This paper is concerned with the first.

Liquid fueled rockets, such as Titan, and solid propellant missiles, such as Minuteman, will be stored in silos in a state of constant alert, with only go-no-go checkout and fuel top-off to be completed prior to elevating and launching. The silos will be hardened to withstand high external blast pressures, as will also the control points. Every silo and control point will be secure from anything but a direct hit of a nuclear warhead. Each of the silos will be weathertight.

This necessary preoccupation with external protection, however, must not obscure one vital internal consideration—the missile must be preserved in the excavation environment. Furthermore, regardless of the time in storage, the weapon must remain substantially invulnerable to corrosion. Corrosion, or chemical deterioration, assumes many insidious forms and can render a missile inoperative as effectively as a direct hit.

For purposes of this paper, corrosion is defined as any type of deterioration caused by the environment, or contributed to by it. This is a much broader definition of corrosion than is normally encountered. Whether mention is made concerning the rusting of metal (which everyone would accept as corrosion) or the weakening of a plastic laminate through the capillary action of moisture following the exposed glass thread, all such reactions of the missile to its environment are lumped broadly under "corrosion."

To ensure reliability, a missile will literally have to be preserved in silo storage. Components of both the missile and the silo support equipment must be exercised periodically. Subsystems and components must be given checkout tests on a periodic, perhaps automatic, basis. Many of the guidance system components and other electronics will be sealed hermetically in pressurized inert atmosphere. However, when the missile is considered in its entirety, the electrical-electronic elements represent only perhaps 50 percent of the possible sources of unreliability.

Structural elements cannot be activated, and it may be difficult to provide access to many vital areas for periodic visual inspection. Mechanical parts will not be maintained in motion, and will be cycled only to a limited degree.

Steel, aluminum, magnesium, copper, adhesives, reinforced plastics, rubber, elastomers, potting compounds, platings, coatings, and corrosion-preventive finishes are all susceptible to eventual attack if a

Mr. Gatzek received a B.S. degree from the University of Chicago and has completed graduate courses at the University of Chicago, Armour Institute of Technology, Massachusetts Institute of Technology, and the University of California. He became associated with the Aerospace Corporation in August 1960 after several years with Space Technology Laboratories as head of Materials Engineering. Prior to that, Mr. Gatzek was head of the Materials Lab. in the Pacific Division of Bendix Corp. He holds memberships in the American Welding Society, American Society for Metals, and the Metallurgical Society of AIME, and is a registered professional engineer. He also is on the faculty of the engineering departments of Los Angeles City College and Valley College.

A review of

- Corrosive atmospheres
- Preventive measures
- Detection techniques

SINCE PREPARATION of this article, several serious failures of stainless steel weldments have occurred in silo installations after encountering corrosive media. All were attributed to several carbide precipitations that resulted from both improper welding technique and unsuitable chemical composition of the parent metal. Precipitated carbides render the material extremely sensitive to subsequent stress corrosion. Fortunately, in each instance, the incorrect procedures and alloy selection actually caused the welded joints in the large diameter stainless steel tubing to fracture completely in the heat-affected zones so that immediate detection and replacement was possible. Too often, such deleterious effects are time and environment dependent, and the progressive deterioration of the affected components is not revealed until they are in service. Thus, stainless steel liquid oxygen fill systems can fail catastrophically after apparently remaining in excellent condition for years, when suddenly exposed to the thermal shock of lox loading just when reliability of the missile becomes critical.

Optimum welding techniques and specific chemical modifications of the austenitic stainless steels are mandatory for reliable weldments. Typical of such compositions is the low carbon Type 304 ELC. With a maximum of 0.03 percent carbon tolerated, carbide precipitation during welding and the accompanying embrittlement or "sensitization" are, thus, minimized.

Sensitization, as the formation of intergranular chromium carbides is known, can occur in varying degrees in most austenitic stainless steels. The severity of sensitization depends on (1) the carbon content of the alloy and (2) exposure time in the 900 to 1,500°F temperature range. Such exposure occurs automatically in the heat-affected zone adjacent to weldments as the molten weld metal pool solidifies.

This deleterious effect of carbide formation (and their subsequent migration to the grain boundaries) is minimized by additions of titanium (Type 321), columbium (Type 347), and molybdenum (Types 316 and 317) which react preferentially with carbon to form more stable carbides than chromium. Lowering the carbon content to 0.03 percent maximum, as in Types 304 ELC and 316 ELC, also reduces the availability of carbon for the chromium carbide precipitation.

Another highly undesirable effect that often accompanies welding of the austenitic stainless steels is formation of the sigma phase at temperatures between 1,350° and 1,650°F. Composed of iron and chromium, the sigma phase is hard and glasslike, and makes weldment brittle and deficient in toughness as the temperature decreases. Table 3 indicates the effect of sensitization and sigma phase formation on the toughness of some unstabilized and stabilized stainless grades.

corrosive environment is permitted to exist.

From the moment a missile is placed in an environmentally unprotected silo, deterioration commences. Missile reliability—i.e., the individual and collective reliability of each and every one of its parts and components—declines as deterioration progresses. Environment within the silo must be controlled to the degree that obviates this aging process. The sources of the deterioration will have to be determined in advance, remedial measures sought, and every action taken to anticipate and correct through environmental control.

Moreover, conflicting conditions may exist. A completely dry atmosphere will prevent deterioration of metal parts. But this same "protection" could be a source of deterioration for cellulose products which require a degree of moisture to retain their form and shape.

It is imperative that maximum reliability be maintained for some minimum period of time. Thus factors which are also functions of time must be carefully considered. Parameters of this class include creep and certain metal- (*Continued on page 87*)

Hawk Hydraulic and Electromechanical Field Maintenance Equipment

Theodore Jacobsohn and Henry A. Matarazzo

Kidde Electronics Laboratories, Walter Kidde & Company, Inc.

Final design of the hydraulic test shop includes (1) hydraulic console, (2) heat exchanger, (3) air compressor and reservoir assembly, (4) degreaser and accumulator test console, and (5) portable filtration unit.

THIRD AND FOURTH ECHELON test equipment for the Hawk missile system consists of electronic, mechanical, and hydraulic test equipment mounted in transportable shelters. Hydraulic and electromechanical shops* contain equipment enabling mechanics to perform tests and repairs on pumps, valves, filters, cylinder assemblies, accumulators, pressure gages and similar components of the launcher, loader, and other support equipment for the Hawk missile. At the battery site, malfunctions of major equipments are isolated to components by battery mechanics. The malfunctioning component is returned to the test shops which are semipermanently emplaced at a field maintenance site near the firing battery (Fig. 1).

To test components properly which have been removed from major assemblies, normal operating parameters are simulated. In order to accomplish this, components are mounted in holding fixtures and connected by hydraulic or pneumatic lines to a test console. When the defective component is integrated into a simulated system, the mechanic, following a defined procedure, is then able to determine the nature of malfunctions, make necessary repairs or recommendations for replacement.

Two primary systems are provided in the hydraulic test shop for simulating normal operating conditions, the hydraulic system, and the pneumatic system. Facilities are also available for cleaning and degreasing components before and after maintenance. The electromechanical test shop contains a diversified selection of tools and standard test equipment permitting a variety of repair operations to be performed (Fig. 2).

The design of the hydraulic test shop was predicated upon test specifications available for the assigned components. To maintain reasonable test equipment configurations, parameters were scaled down for components requiring operating ranges exceeding those of the majority of components.

The final design of the hydraulic test shop includes the following major items: (1) hydraulic console, (2) heat exchanger, (3) air compressor and reservoir assembly, (4) degreaser and accumulator test console, and (5) portable filtration unit (Fig. 3).

* Kidde Electronics Laboratories (of Walter Kidde & Company, Inc.), under contract with and the guidance of Raytheon Company, Hawk Missile Systems Manager, is building transportable hydraulic and electromechanical test shops.

Theodore Jacobsohn, assistant manager of Kidde Electronics Laboratories, Walter Kidde & Company, Inc., received his B.S. degree from Massachusetts Institute of Technology in 1951. Prior to his present affiliation, he was Senior Engineer at Avion Division, ACF Industries, and Product Engineer at Allen B. Du Mont Laboratories, Inc. Mr. Jacobsohn specializes in the design and production of electronic, electromechanical, and ground support equipment for missile and aircraft systems.

Henry Matarazzo, assistant chief mechanical engineer of Kidde Electronics Laboratories, Walter Kidde & Company, Inc., received his B.S. degree *cum laude* from Fairleigh Dickinson University. Previous to his current affiliation, he held the position of electromechanical designer at Bendix Aircraft Corporation as well as at Curtiss Wright Corporation. He specializes in the design of aircraft accessories, electromechanical equipment, and ground support systems.

Hydraulic Console

The hydraulic console is designed to provide a range of flows of MIL-H-5606 oil from 0 to 8 gpm. It is also capable of providing static oil pressures to 6,000 psi through a hand pump system. The power system comprises a reservoir, a manually controlled variable displacement pump, fine and coarse throttling valves for pressure control, flowmeters for measuring volumetric flow, gages for monitoring oil pressure, a manually adjusted system pressure relief valve, supply and return ports connecting components under test and a heat exchanger external to the console. Auxiliary equipment (Fig. 4) includes filters, an accumulator, and relief valves.

The power input required by the console is 416 volt, 400 cycle, 3 phase. An electric junction box is located on the lower left-hand side of the unit. A power input connector and a connector supplying power to the heat exchanger are on this panel, as are circuit breakers protecting the system pressure pump, oil heater, and heat exchanger.

Control of these units is normally accomplished by thermostatic switches in the main oil reservoir. One switch permits heater operation at oil temperatures below approximately 20°F. A second switch prevents pump operation below oil temperature of 0°F. A third switch turns on the heat exchanger at oil temperatures in excess of approximately 100°F. Normally, the heat exchanger prevents the oil from reaching high temperatures; however, as a safety factor, a fourth switch in the pump motor circuit will shut the pump motor off at oil temperatures in excess of 165°F. The electric system is isolated physically from the atmosphere inside the console as a safety precaution. (*Continued on page 90*)

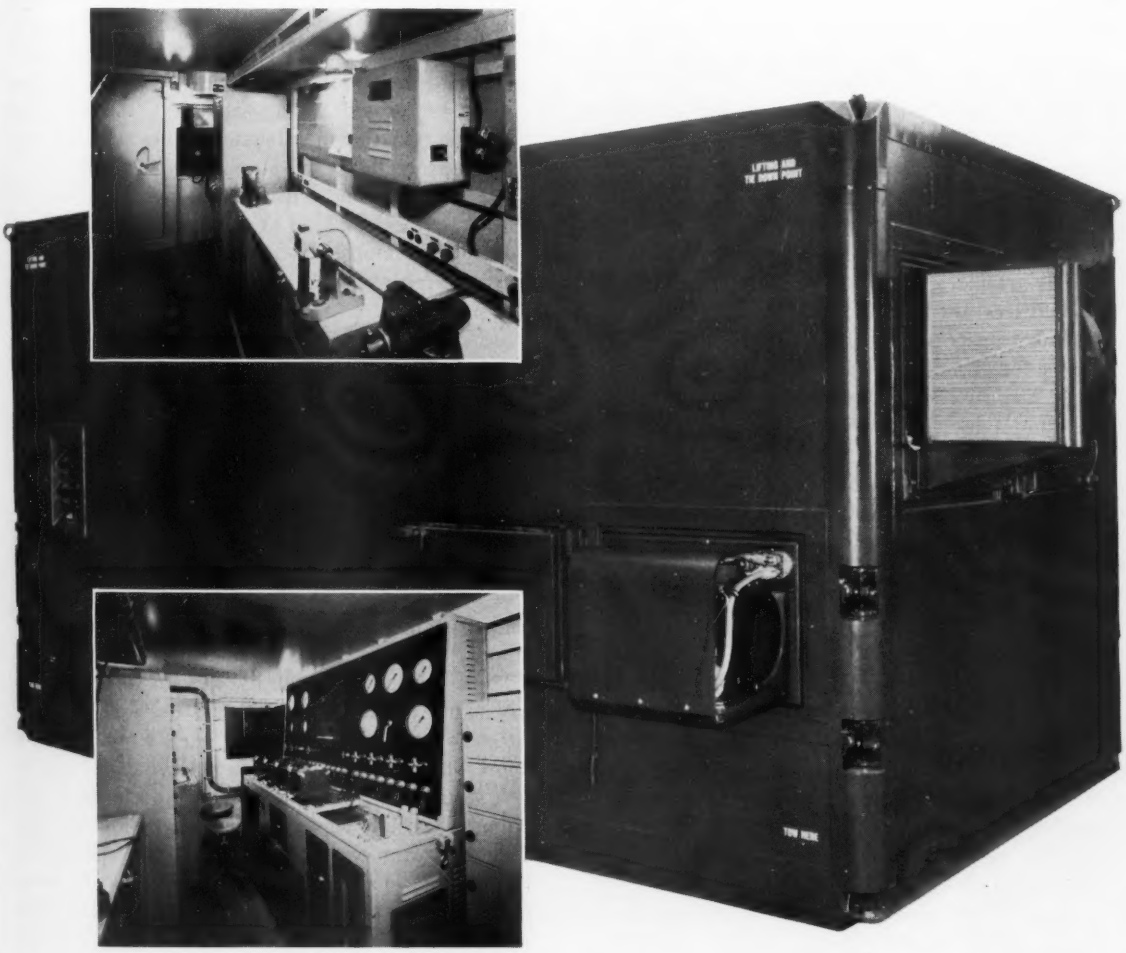


Fig. 1. Exterior view of basic transportable test shop in support of Hawk missile system. Dimensions: 188 in. long, 81 in. wide, 83 in. high. Heat exchanger (upper right), air compressor and housing (left) are in operating position. Fig. 2. Interior view (*top insert*) of electromechanical test shop. Shown are work benches with vises, small arbor press, and transformer box. Fig. 3. Interior view (*bottom insert*) of hydraulic test shop, showing console, heat exchanger (upper background), and cabinets.

Operation Non-Routine

Maintenance Support Trends of Subsonic and Supersonic Transports

"A plan is implemented to have specific parts, maintenance talent, and ground test equipment on hand for corrective action upon arrival of the airplane. This achieves a planned non-routine maintenance operation."

P. A. Hartline, *Trans World Airlines, Inc.*

REVIEW OF commercial experiences encountered in the transition of the air transportation industry from piston-powered aircraft to subsonic jet confirms that the most challenging aspect for the subsonic and supersonic era is what we have called *Operation Non-Routine*. This term, as we are using it, should be defined as the means of combating flight interruptions and cancellations—i.e., those non-routine occurrences which delay or cancel achievement of the planned mission. You may ask why flight interruptions are more important now than in the past. Subsonic jets are twice as large and twice as fast as piston transports, which makes their productive capacity four times that of each piston-powered aircraft. The supersonic transport will have twelve times the productive capacity as the piston aircraft.

It is therefore apparent that each flight interruption or cancellation will adversely affect production over the contemporary piston aircraft by a factor of 4 for the subsonic transport and 12 for the supersonic.

What action was initiated to combat this factor with the subsonic jet operation?

(1) The primary design objective of the airframe manufacturers was to meet each requirement with a simple design. Since it is so much easier to achieve design requirements if one accepts complexity, this goal can be attained only by perseverance and ingenuity.

(2) The airframe manufacturers used components with proved reliability wherever possible.

(3) Laboratory reliability testing was required of components prior to acceptance.

(4) Because of the increase in complexity of the systems—i.e., flight control, electrical, electronic, navigation aids, instrumentation, structures, etc.—it was necessary to expand airline field technical specialist coverage to include a specialist in each of these areas. Prior to the jet, only power-plant specialists were provided in the field. All of these specialists provide 7-day-a-week, 24-hour-a-day coverage at major maintenance bases. (TWA provides these teams at five stations.)

(5) Hand-in-hand with the foregoing, it was essential that better lines of communication be established to accomplish the following:

(a) Permit utilization of this specialized talent by the smaller stations when they encountered non-routine problems.

(b) Permit exchange of experiences, knowledge, special techniques, etc., throughout the airline so that, if similar conditions occurred at any station, it would be prepared to handle the matter in most efficient manner—i.e., by non-routine planning.

(c) Permit utilization of central engineering personnel for the ultimate in specialization for field assistance when needed.

(d) Permit timely feedback of repetitive failures to central engineering staff for initiation of corrective action.

These needs were met by the installation of a private line phone system for maintenance personnel.

(6) To keep a tight rein on each jet airplane, a report via private phone and teletype message to each station en route and to the Maintenance Coordinator in the central region is completed immediately after each departure. Upon receipt of this information, a plan is implemented to have specific parts, maintenance talent, and ground test equipment on hand for corrective action upon arrival of the airplane. This achieves a planned non-routine maintenance operation.

(7) Specialized tooling has been developed and

utilized on a routine as well as non-routine basis. Examples of this tooling are the fuel quantity capacitance testor, generator system analyzer, Freon control system analyzer, automatic flight director system analyzer, and engine power analyzer.

This equipment is used on a scheduled maintenance basis to detect, correct, or replace any component within the specific system which has deteriorated to tolerances or adjustments out of acceptable new component standards. This effort periodically rejuvenates the system and has proved to reduce the non-routine activities by removing units prior to complete failure.

This equipment is also a much needed tool for use by maintenance personnel in solving system problems which do not respond to normal treatment.

How effective have these steps been in meeting subsonic aircraft needs? Performance to date has shown that daily utilization of the jet has increased from a planned 8 hours per day to 10.5 hours per day, with an increase in mission reliability. This effort, therefore, has effected an increase in productivity of 30 percent with no loss in product reliability.

What additional action is necessary for the supersonic transport?

(1) Install automatic in-flight recording instrumentation on critical and expensive components such as engines, constant speed drives, generators, etc. This is required (a) to provide accurate data to assist in trouble shooting and achieving effective preventive maintenance, and (b) to relieve the flight crew of the need to record these data so that their efforts may be directed to other instrumentation and associated in-flight checks to resolve the cause of any problem. This in-flight analysis will permit immediate corrective action by ground personnel since data will be known.

(2) Provide additional instrumentation for major systems to permit in-flight diagnosis of malfunctions so that ground maintenance personnel can fix system solely on information provided. This eliminates necessity for time-consuming engine run-ups, flight tests, etc.

(3) Add aircraft provisions for sandwich panel inserts in all complex electrical and electronic circuits. The ground instrumentation jeeps which plug into these provisions will be designed to check qualitative and quantitative performance of the function of each component—i.e., duplicate shop test requirements insofar as practical.

(4) Achieve sound, effective designs initially. Experience proves that the design engineer knows much about why the system will work but that he usually gives little thought to (a) whether fail-safe provisions are adequate; (b) what the weak points are and what can be done to correct them; and (c) how one can check that each component is working via a routine maintenance program, or whether this can be done more simply.

(5) Achieve effective technical specialist training. This is a new endeavor and much effort by the airframe company, component manufacturers, and airlines will be required well in advance of scheduled supersonic jet flights.

To date, training of the quality and type needed has not been available from any source. Technical knowledge has been gained through the hard knocks of experience—i.e., unnecessary, lengthy, costly flight delays. To achieve the needed non-routine planning, training must include the following over and above present system description training:

(a) Analysis of system failures by considering each component failure separately as to its effect on operation of system and instrumentation presentation.

(b) Provision of detailed analysis of units within components to develop effective trouble-shooting schemes.

(6) Achieve high level of reliability. Although sound design is an essential requirement, quality control during component, subassembly, and final assembly is the key to achieving reliability. To this end, company management will have to create a "will to do" by each employee.

(7) Provide for quick accessibility and replaceability of each component. To achieve this goal, work should be initiated now to develop quick-operating, stress-carrying panel attachment means.

(8) Provide tooling and devices such as the following:

(a) A device which will detect the intermittent electrical connection fault such as poor connection of a wire splice, cold solder joint, etc.

(b) A device which will detect metal fatigue or physical damage of wire conductor, aircraft cables, continuous fire detector elements, etc., without removal from aircraft.

(c) Measuring devices which will permit accurate airframe determination of transient loads within mechanical dynamic units and electrical circuits. Too many failures of diodes, landing gear units, etc., are encountered which (*Continued on page 94*)

Mr. Hartline is Manager of Maintenance Engineering for Trans World Airlines, Inc. He has a B.S. degree in aeronautical engineering from New York University (1946). Prior to joining TWA, he served as a maintenance officer in the Air Transport Command during World War II and as a Design Engineer for Republic Aviation. He has broad technical experience in the design of aircraft mechanical systems and, in his present position, directs the Maintenance Engineering activities for the complete airframe.

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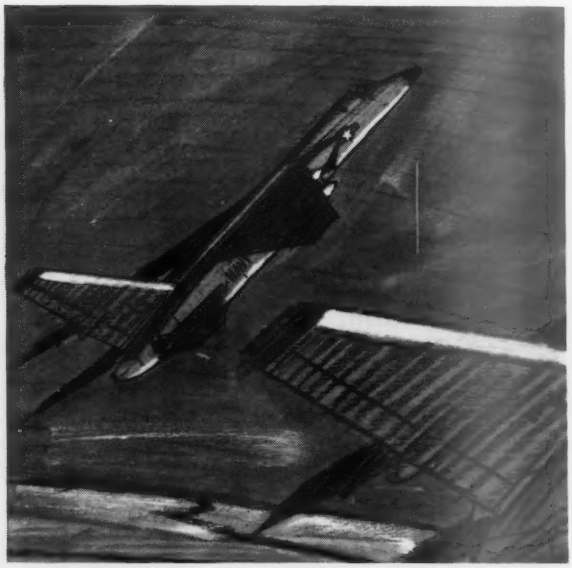
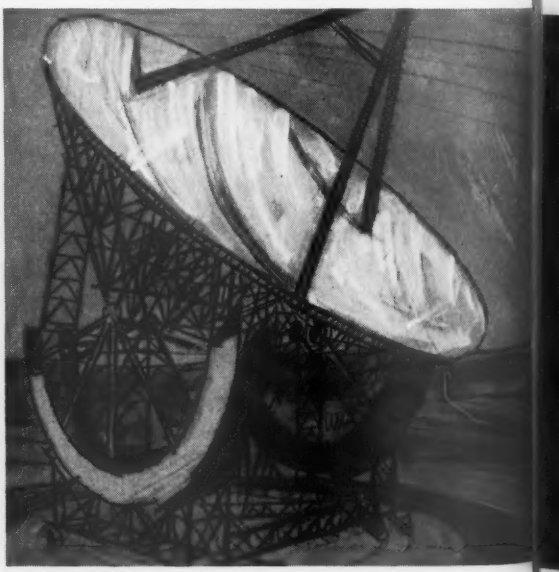


A3J VIGILANTE. Navy's A3J set a new world's record, flying to 91,450 ft. carrying a payload of 2,204 lbs. The versatile, carrier-based A3J can perform high or low level missions in any weather, from any attitude, day or night.



THE BIG "EAR." World's largest radio telescope reflecto six hundred feet in diameter, is being built by Columb for the Navy in Sugar Grove, W. Virginia. Columbus also building a complete antenna system for the USA

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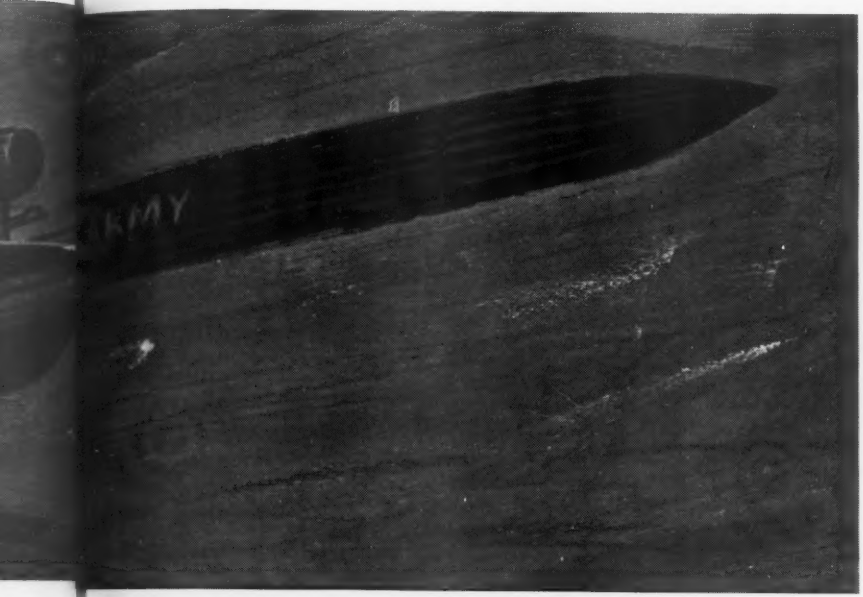
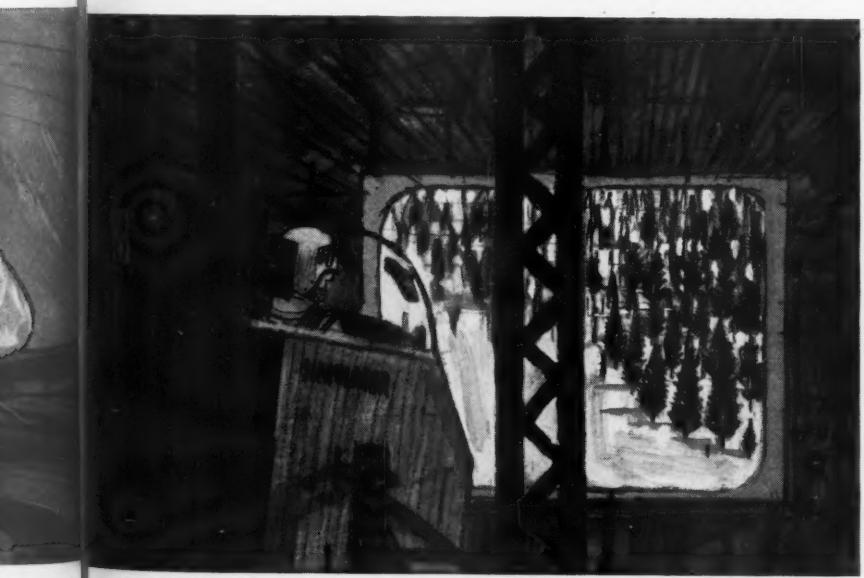


TWO-IN-ONE TARGET MISSILE. New target missile NA-273 can carry out high- or low-level missions equally well. It performs from ground level to 60,000 feet, and from subsonic through Mach 2. Under development for the Army by the Columbus Division, it is launched by a rocket, and powered in flight by ramjet.



V/STOL FACILITIES. New six-degree-of-freedom flight simulator is part of facilities set up by Columbus Division to study requirements of vertical and short takeoff and landing aircraft design and development. Other V/STOL facilities include low-speed to transonic wind tunnel and unique lightweight ejection seat.

Titan Facilities

(Continued from page 11)

the missile; a portal which is the principal means of egress and ingress; and two antennas which provide for the guidance of the Titan during its powered flight. These structures are all buried below the surface of the ground and are interconnected by means of steel tunnels (Figs. 1 and 2).

When these complexes become operational (the first is scheduled for later this year) and are in a state of readiness, the only access to the facilities from the ground surface will be at the portal, through which will enter personnel and supplies, the air intake and exhaust structures which will handle air for personnel and equipment, and combustion air for the power generators. All vents or air intake shafts to the surface are provided with blast valves. These valves will close automatically within 1/2 sec after blast or after radiation-sensing devices topside record external disturbance.

Should a command be given to launch a Titan, the missile would be filled with LOX (the RP-1 being stored in the missile itself), the missile silo closure would open, and the missile would be lifted to the surface on an elevator and launched from above ground. All this is accomplished remotely from the control center. Blast locks are provided between each of the three launchers so that in the event that one missile is exposed during attack or should abort, the remaining missiles in the complex would not be damaged by the blast pressure wave (Fig. 3).

Launcher Area

Missile Silo

The missile silo is a reinforced concrete cylinder, 40 ft in diameter, 161 ft deep. The wall thickness is 24 in. and tapers to 13 ft 9 in. near the ground surface to accommodate the high thrust loads occasioned by opening the double-leafed hinged closures. Each leaf of the closure is reinforced concrete $16^1/_2$ ft by 24 ft by 42 in. thick, weighs 106 tons, and resists some 50 million lbs of vertical load. The base slab or footing varies from 6 ft 0 in. to 8 ft 0 in. thick, depending on soil conditions (Fig. 4).

Construction methods generally varied with the General Contractor. At Lowry AFB, forms were of prefabricated wood, and concrete was poured in 12- to 15-ft lifts. At Vandenberg AFB, where the OSTF and Training Facilities were located, and at Ellsworth AFB, the Contractor chose to use "slip form" method of construction.

The cost of each missile silo—in-

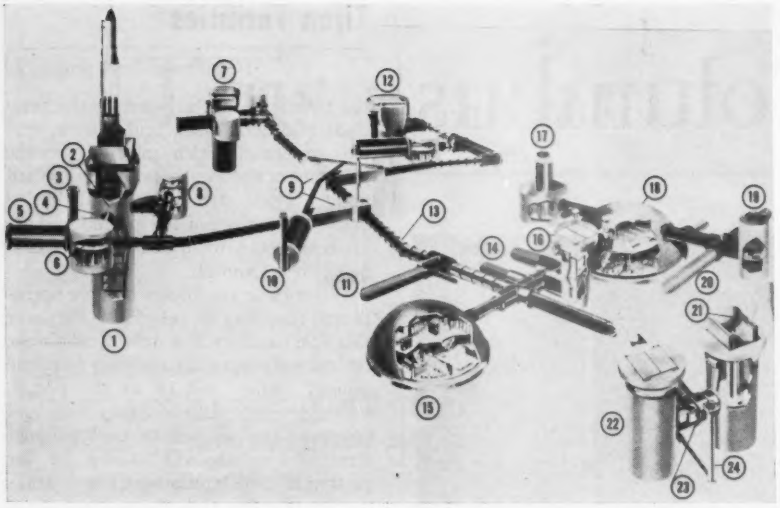


Fig. 3. Titan launch complex consisting of: (1) Launcher No. 1, (2) missile silo, (3) vent, (4) connecting tunnel, (5) LOX tank, (6) propellant terminal, (7) Launcher No. 2, (8) equipment terminal, (9) blast locks, (10) launcher area air filtration facility, (11) RP-1 tank, (12) Launcher No. 3, (13) personnel tunnel, (14) water tanks, (15) control center, (16) entry portal, (17) powerhouse air filtration facility, (18) powerhouse, (19) powerhouse exhaust facility, (20) diesel fuel tanks, (21) antenna, (22) antenna silos, (23) antenna terminal, and (24) exhaust vent.

cluding the structure, piping, and utilities, but excluding the steel "crib" or tower, flame bucket, elevator, and closure mechanisms—approximates $845,000. Some 4,000 cubic yards of concrete and 700 tons of reinforcing steel are required for this structure.

The missile is supported on a steel "crib" weighing approximately 480 tons which in turn is supported on eight spring shock mounts attached to the concrete wall. These springs are furnished in sets of three concentric springs with the outermost made of 3-in.-diameter stock coiled to a diameter 22 in. wide and 49 in. long. The spring constant for this assembly is 200,000 lbs/in., and each is attached to a 1,500-lb embedment by means of a $3^3/_4$ in.-diameter threaded upset rod. This shock-mounted assembly is designed to attenuate shock transmission to the missile to a very low magnitude. Provisions have been made to permit the "crib" motion in a 2-ft envelope under actual external blast conditions. All electrical and mechanical connections and piping from the facilities to the missile have therefore been made flexible (Fig. 5).

Propellant Terminal

At a distance of 40 ft south of the missile silo, we have located the propellant terminal, a cylindrical structure 40 ft in diameter and 40 ft in depth. The propellant terminal houses the gaseous oxygen transfer system, the valving required to load the missile with LOX at a rate of 3,600 gpm, as well as the helium cooler and the gaseous nitrogen.

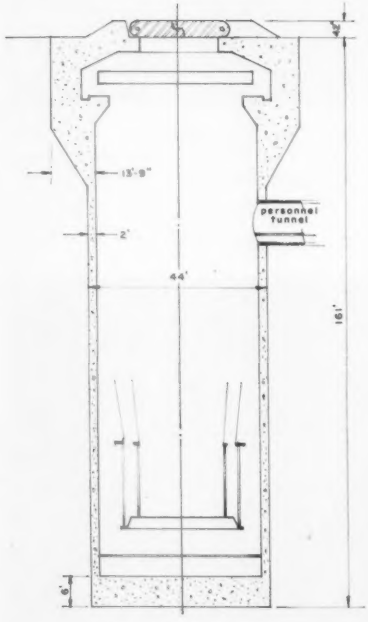


Fig. 4. Missile silo.

The LOX storage tank (26,500-gal capacity) is in an appendage separate from the propellant terminal and is supported on a structural steel frame which acts as a shock mount. This tank has an inner lining of stainless steel Grade "S" A 240, and an annular 12-in. space between the inner tank and the Grade "C" A 285 outer tank. The inner tank is supported by a three-point suspension system of small stainless steel straps. The annular space between the two tanks is filled with a granular insulating material such as vermiculite and is drawn under a partial vacuum. The specifications required a maximum heat loss of 1/4 of 1 percent per day. On the first squadrons at Denver, the minimum frequency permitted of the tank assembly was 25 cps. To attain this frequency, stiffener rings of appreciable moment of inertia were required on the outer shell. On subsequent squadrons, this requirement was waived.

The walls of the propellant terminal are 18 in. thick with a roof slab of 6 ft and a foundation slab $6^1/_2$ ft. A 10-ft-diameter temporary opening is provided in the top slab for installation of large tanks and vessels. The floors and equipment are all shock mounted.

The cost of this structure approximates $415,000. The equipment contained within the structure and the tankage, valving, and piping represent additional cost in each structure of $880,000.

Equipment Terminal

The equipment terminal, a four-story structure, is located some 45 ft to the northeast of the missile silo. Contained in this structure are the hydraulic equipment which actuates the opening of the missile silo closure, air-conditioning equipment to keep the missile itself and some of its components under strict temperature and humidity control, the launch checkout equipment and relays, primarily electronics, and the launcher power equipment and switchgear which provides for the actual raising of the fully loaded missile on

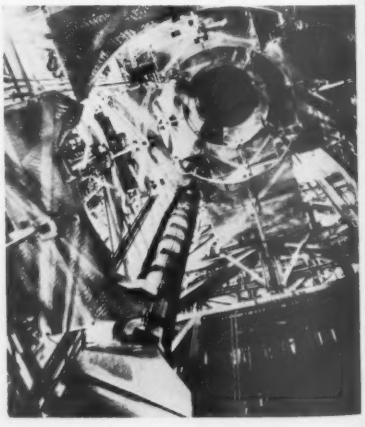


Fig. 5. View of missile silo interior, looking skyward, shows steel crib with work platforms. Umbilical tower extends from lower left of picture to center and rides up elevator connected to missile (not shown) prior to launch. There are approximately 34 connections to missile from umbilical tower, all of which disconnect automatically just prior to launch. (Fortune *photo by Fred Swartz.*)

its elevator. All floors of the equipment terminal are suspended by hangers from the midpoint of spring beams located below the floor girders of the floor above, which in effect, provides for shock attenuation. The lowest floor rests on spring beams supported directly from the foundation slab.

The equipment terminal structural features, except for overall height, are similar to the propellant terminal.

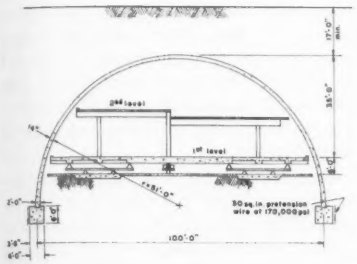


Fig. 6. Control center, showing first and second floors. Spring beams attenuate accelerations resulting from blast loads to a 3g level. Some of the sensitive electronic equipment requires additional isolation mechanisms to reduce accelerations even further.

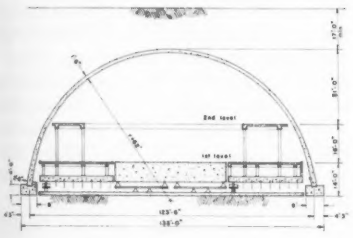


Fig. 7. Powerhouse, showing first and second floors designed with spring beams similar to control center.

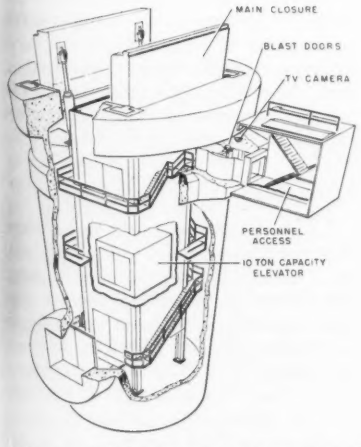


Fig. 8. With launch complex in operational readiness, portal silo is only means of ingress or egress for personnel, supplies, and equipment.

Walls are 18 in. thick, the roof slab 6 ft thick, and the foundation slab 7-ft thick. The structure is 43 ft in diameter and $70\frac{1}{2}$ ft deep and costs approximately $400,000 each.

Tunnels

There are approximately 2,900 ft of tunnel section interconnecting all the buried structures in each complex. In general, the tunnels are of steel multiplate when placed in open-cut excavation, or liner plate when drifted. At the Vandenberg and Beale bases, because of the nature of the soil, the Contractors chose to mine for the tunnels in lieu of the open-cut method. At the other bases, tunnels were placed in open cut.

Tunnels vary in diameter from $16\frac{1}{2}$ ft to 4 ft, with the major portion being $9\frac{1}{2}$ ft. The tunnels are used primarily for personnel access and transportation of tools, checkout equipment, and replacement parts and contain the required utility lines needed at the various structures. The $16\frac{1}{2}$ ft tunnel section also houses relay stations. Tunnel plate is covered with asbestos-impregnated asphalt, $\frac{1}{8}$ of an inch thick on the exterior surface. The plate thickness varies from #10 to #1 gage.

Blast locks are provided at the main tunnel intersections to prevent a mishap at any one launcher from affecting other structures. These blast locks are reinforced concrete and contain electrically interlocking steel blast doors so controlled that only one door of a spaced pair may be opened at any one time. (The design of these blast doors was proved by the unfortunate explosion at OSTF December 3, 1960. The missile, equipment terminal, and propellant silos were destroyed beyond repair, but the blast doors prevented damage and injury to equipment and personnel beyond.)

Construction of the tunnels involved some 925,000 cubic yards of excavation and 3,400 tons of structural steel for each complex at a cost of approximately $1,750,000. Included in this cost are the shock-mounted floor and pipe support system and all facility-provided piping and utilities.

Control Center

The nerve center of each launch complex is located at the control center. Within this domed structure spanning 100 ft are located the necessary communication equipment, control and launch consoles, automatic readout equipment, computers, and the personnel necessary to operate the complex. Spare parts ("black boxes") for rapid replacement of any malfunctioning part of the GSE or the missile itself are stored within this structure. Some 230 functions of checkout are

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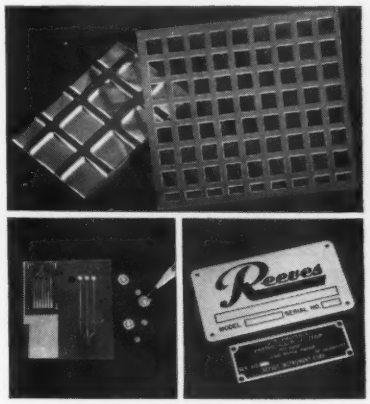

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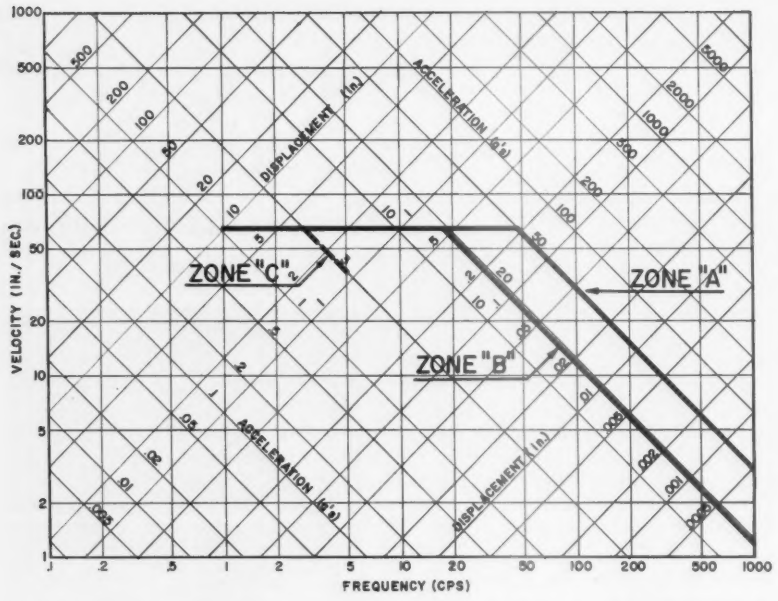


Fig. 9. Horizontal and vertical response spectra, showing plot of velocity, accelerations, and displacements for each zone within the facilities.

performed in the control center, equipment terminal, and antenna terminal.

The first and second levels of the control center are supported on spring beams and provide shock attenuation for the fragile electronic equipment supported thereon. Both floors are also isolated from the domed structure itself to minimize shock transmissibility through the external shell.

The domed structure is of reinforced concrete 14 in. thick at the crown and thickening to 24 in. at the foundation slab (Fig. 6). After detailed field tests were made, the footing size was determined on the basis of an allowable dynamic soil pressure of 70,000 psf. On the basis of these tests, it is expected that the entire domed structure will displace under full blast loading conditions thus absorbing a great portion of the energy to which it is exposed.

This structure required the excavation of 60,000 cubic yards of earth, 1,800 cubic yards of concrete, and 130 tons of rebar. Construction cost totaled $620,000.

Powerhouse

Located approximately 120 ft to the east of the control center is another domed structure, the powerhouse, spanning 123 ft (Fig. 7). The powerhouse provides for all the utilities necessary to sustain each complex without support for up to 2 weeks. Water wells located within this structure extend to a depth of 1,200 ft in the Denver area and at varying depths elsewhere, and provide necessary water for domestic use and air conditioning. There are four 1,000-kw diesel engine generators which provide all the power required to operate and sequentially launch three missiles after a simultaneous countdown.

The need for air conditioning is critical. In order to function with required reliability, electronic equipment must be maintained with consistent temperature and humidity. Since the air-conditioning requirements are at their peak only during the countdown prior to launch, it was decided to furnish "ice banks" for the storage of cold water for these peak conditions. The storage of 45 tons of ice has been provided at the Denver sites and 30 tons at the others.

One of the most challenging problems associated with the design itself involved the shock mounting of the heavy powerhouse equipment. Both the first level and the mezzanine level are supported in a manner similar to the floors of the control center. In addition to the shock attenuation provided by the spring beams, additional attenuation and damping have been provided by coil springs placed below some of the heavy operating equipment. Visualizing a power plant of sufficient size to accommodate a community of 5,000, with the maze of interconnecting conduit, piping, and equipment, and recognizing that all equipment must remain operative when subjected to high-intensity external shock loads, one realizes that this support center was one of the most complicated design problems.

The concrete dome for the powerhouse varies in thickness from 18 in. at the crown to 30 in. at the foundation level. This foundation, similar to the control center, has been designed to displace under the blast loads.

Each powerhouse and air intake and exhaust structure involved 180,000 cubic yards of excavation, 8,400 cubic yards of concrete, 1,000 tons of rebar, and 780 tons of structural steel. The construction cost including equipment totaled $3,100,000.

Portal Silo

Halfway between the powerhouse and control center is the portal silo, $29\frac{1}{2}$ ft in diameter by 75 ft deep. The closure at the ground surface capping the portal functions similarly to the missile silo closure and the antenna silo closure and is reinforced concrete 42 in. thick. Contained within this silo are personnel stairs and a 10-ton freight elevator. Personnel have access to the entire facilities through the personnel appendage to this structure. Blast doors are strategically located to prevent damage to the facilities in the

Fig. 10. Aerial view of typical launch complex, looking south, shows three launcher areas in foreground, powerhouse to left of control center at middle, and two antenna silos in background.

event of an attack with the main closure or personnel access open (Fig. 8). Closed-circuit TV cameras are used to identify those entering the facility. Construction cost approximates $250,000.

Antenna Terminal and Silo

Two antenna silos with a single terminal are provided some 600 ft south of the control center and powerhouse structures. These antenna silos house the radio inertial guidance radomes which determine the path of the missile during its powered flight. Prior to launch, with the missile in a raised position, one radome is elevated and locks onto the guidance compartment of the missile. The radome remains above ground until the missile is in a ballistic trajectory, after which the radome is lowered and the concrete doors are closed.

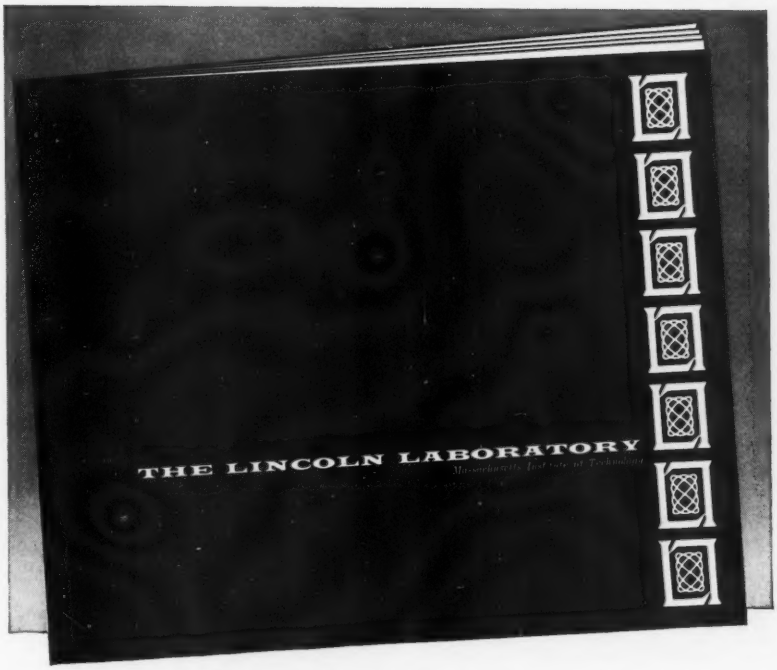
The second antenna silo is primarily stand-by in the event of either a malfunction of the first radome or an attack when the radome is in the up or "soft" position. The antenna terminal houses the relay station for control of the radome remotely from the control center. The structure for this terminal is a large section of tunnel $16\frac{1}{2}$ ft in diameter.

The antenna silo is structurally comparable to the portal silo with respect to the closure and general configuration. The walls are 15 in. thick and the foundation slab 6 ft thick. The radome is shock mounted on a spring suspension system similar to that supporting the "crib" in the missile silo but smaller.

Shock Mounting

Extensive use was made of seismic explorations as the basis for determining maximum vertical and horizontal displacements, accelerations, and frequencies to which the structures would be subjected. The Air Force's Senior Panel of Engineering Consultants assisted in the evaluation and application of the subsurface exploration data to the problems of estimating the transient and permanent displacing of nonhomogeneous materials such as earth and rock. This Senior Panel included Dr. Nathan Newmark and Dr. Ralph Peck, University of Illinois; Dr. Robert Whitman and Dr. Hansen, M.I.T.; Dr. Robert Vaile, S.R.I.; Mark Peter, C.I.T.; Dr. George Housner, Dr. Ben Sussholz, and Dr. Millard Barton, S.T.L. Dr. Sussholz acted as Chairman of this Panel for Col. D. S. Chamberlain, Project Officer for AFBMD Installations.

Shock spectra developed by this group formed the basis for the A-E design, as well as the GSE design accomplished by the missile manufacturers. The response of the primary structures and the floors to the



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shock input was made available to the General Contractors in the specifications (Fig. 9). Equipment located in various parts of the facilities was then identified with the shock input that would be transmitted to it. Additional attenuation, therefore, for the specific equipment provided became the responsibility of the Construction Contractor.

The exterior walls of the structures (silo walls, domes, and tunnels) were designated as Shock Zone "A," and items mounted directly thereto would be subject to a maximum acceleration of 50g. Zone "B" applies to facility piping "cribs" in the missile silo. Shock-mounted floors designated as Zone "C" would transmit accelerations in the order of 3g.

The Contractor then was given the option of either strengthening the equipment where necessary or further isolating it by springs or other means. Physical testing of the equipment to determine its ability to function during and after the anticipated shock load was a further requirement.

Accidents

Considering the magnitude of this program, the number of accidents that have occurred during construction have been minimal. In Denver, the antenna closure at one complex was dropped during a lift by crane causing damage to the door and the door foundation. The door required replacement, and the cracked foundation was repaired. During excavation for a missile silo at Mountain Home AFB, a crane at the surface toppled down a completely excavated shaft, demolishing both the skip loader in the bottom and the crane itself.

Perhaps the most costly accident occurred at Vandenberg on December 3, 1960. After construction was complete, a series of tests were being performed at the Operational System Test Facility when a fully loaded missile, being lowered into the missile silo, began to accelerate beyond the safe limit. The missile "bottomed out" on the foundation of the missile silo causing a tremendous explosion. The missile silo, equipment terminal, and propellant terminal were demolished beyond repair. Estimates of damage approximate $8 to $10 million. That launcher area will be abandoned.

Conclusion

It is difficult to compress some 900,000 A-E manhours and $225,000,000 worth of construction into these few printed pages. In retrospect, many studies, designs, reports, and other paper work were generated to accomplish the final A-E product. Criteria for A-E design in the form of classified reports were provided by the Air Force and totaled over 1,200 in number. The amount of unclassified material submitted as criteria has never been counted. The blueprinting bill alone for 2 years' effort was over $200,000. This did not include the printing of the final plans and specifications for bidding and construction purposes which was handled by the Corps of Engineers. On one squadron, at Mountain Home AFB, over $3\frac{1}{2}$ tons of plans and specifications were shipped to prospective bidders.

The Titan I construction volume of almost $225 million represented almost 30 percent of the Department of Defense total construction budget over the last 2 years. The following material quantities were involved in the first six Titan squadrons and may be of interest:

Excavation	15,000,000 cubic yards
Concrete	576,000 cubic yards
Reinforcing	78,000 tons
Structural steel	66,000 tons
Tunnel plate (ST)	11,000 tons
Stainless steel	3,000 tons

Because of the concurrent research and development and A-E design, there were numerous design changes necessary during the progress of the work and during the construction phase. The Air Force goal was to have a facility available for occupancy by the Strategic Air Command, one that was invulnerable to thermonuclear attack, at such time as the missile itself became operational. Over 2 years' time was saved as a result of this "concurrency" approach.

Notwithstanding the tremendous cost and effort expended on these missile bases, let us hope that the United States need never put them to the ultimate test.

✦ ✦ ✦

Vertical Floating Launch of Rocket Vehicles (Continued from page 13)

would require considerable development effort merely to solve servicing and ice-accretion problems.

Vehicle Construction, Handling and Logistics

The basic philosophy adopted in the development of the sea-launched concept has been to work with, instead of against, nature as much as possible. Accordingly, a maximum advantage is taken of the continuous support afforded by floating the rocket vehicle and the technique of erecting from a horizontal to a vertical attitude by means of buoyancy control.

Large rocket vehicles destined for sea launch could be constructed in more or less conventional manner in present-day dry docks by use of the segmented principle (Fig. 2). For a longer-range program it would be advantageous to combine a solid-propellant curing pit with a special-purpose dry dock (Fig.

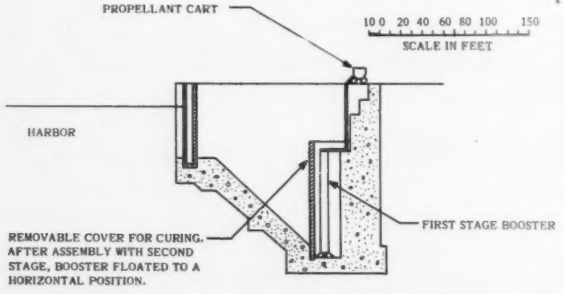
PROPELLANT CART
0 20 40 60 80 100 150
SCALE IN FEET
HARBOR
FIRST STAGE BOOSTER
REMOVABLE COVER FOR CURING. AFTER ASSEMBLY WITH SECOND STAGE, BOOSTER FLOATED TO A HORIZONTAL POSITION.

Fig. 3. Curing, assembly, and flotation of large solid rocket by use of modified or new construction dry dock.

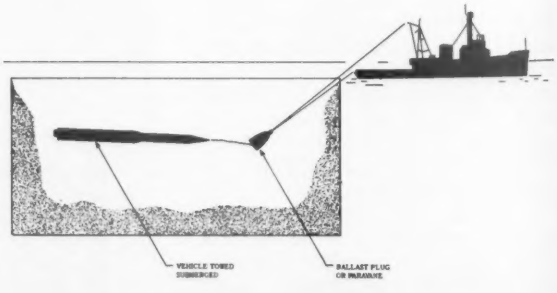

Fig. 4. Underwater towing of solid rocket vehicle to launch site.

3). By means of this facility, the rocket booster may be floated after curing and inspection so that no lifting machinery is required.

Transportation to the launch site may be carried out in several different ways. The first possibility is the bare tow of the booster rockets, less upper stage payload (Fig. 4). An underwater tow is preferred to avoid excessive "hogging" and "sagging" stresses and also to minimize corrosion problems. This method ultimately involves attachment of the payload to the boosters by means of a catamaran or similar vessel at the launch site.

Another promising method for accomplishing transportation and assembly would be the use of a floating dry dock, of which there are several varieties in existence, or a dry-docking ship, such as the Navy's Landing Ship Dock (LSD) type of vessel. By use of this equipment, and techniques similar to the docking and undocking of ships, extremely large rockets may be completely assembled at the launch site, or during transit to the launch site, and placed into the water a few hours prior to launch time (Figs. 5 and 6).

When using the undocking method from a floating dry dock or LSD-type ship, the rocket would be floated clear in a horizontal attitude, fully assembled and checked out as completely as possible. Waterproofing could be used to protect the sophisticated upper stage payload, until vertical erection placed the entire upper stage above the water line (Fig. 7). This temporary waterproofing could then be removed, and access to the upper stage gained by means of a temporary work platform attached directly to the booster vehicle.

The extremely flexible utilization of existing tugs, mobile dry docks, ship- or barge-shop facilities, and range instrumentation ships would certainly be the most economical way of gaining an equatorial launch facility. One or two large mobile dry docks could be stationed on the equator to receive, assemble, and check out rocket vehicles and payloads. Large solid boosters could be towed to the launch site from manufacturing sites on the United States coast by means of conventional tugs and the bare tow technique described earlier. On arrival, they could be docked and then assembled inside the floating dry dock in a dry, horizontal attitude.

The difficulty of checking out the payload can be overcome by accomplishing as much of the checkout as possible while the entire vehicle is in a floating dry dock, reserving only final checkout items to be verified in the vertical, floating condition. A maximum use of automatically programed checkout equipment is contemplated, with the majority of the equipment aboard a support ship. The connection with the

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Table 1. Comparison of Land-Launched Versus Water-Launched Systems

Land-Launched	Water-Launched
Relatively close to populated areas.	Can be removed from population by any desired distance.
Firing bearings may be restricted because of fallout pattern of upper stages.	Launch site may be chosen to permit desired firing bearings.
Transport and logistics must be carried out mainly on highways, railroads, etc., creating some hazard and much inconvenience to populace.	Transport and logistics are at sea, limiting immediate hazards to personnel in the construction and assembly area only.
Significant physical handling is necessary, including much lifting; manufacturing plant to railroad, railroad to launch pad, gantry erection, etc.	Handling is simplified by utilizing floating dry docks and LSD-type ships to carry the vehicles, or by towing the vehicles.
Requires expensive, specially designed handling equipment.	Standard ships now in existence can tow and erect.
Complicated erection procedures involving high localized stresses with much ground-support equipment for erection.	Water erection is accomplished automatically and naturally as a result of the vehicle's positive metacentric height.
Large, expensive launch facility is required, including gantries, armored blockhouses, LOX manufacturing plant, LOX and fuel storage facilities, and water-cooled concrete launch pads.	No-cost, self-healing launch pad. Support ship can back off suitable distance and act as blockhouse.
Access to all portions of the booster and upper stages is facilitated by being on land. Solid or liquid boosters are practical.	Access to lower stages is severely restricted. Utilizing a jet-head type of control system where the nozzles on the boosters are fixed makes access to the lower stages unnecessary. Payload and control section are above the waterline, and access is achieved by attaching a working platform directly to the vehicle.
Electric lines not exposed to moisture other than rain.	Electric lines must be protected from salt-water environment.
Staging is limited by practical considerations.	Since length is no problem, full advantage may be taken of staging. Five to six stages (all solid) should prove practical.
Structure not exposed to a severe corrosive environment.	Structure may be exposed to salt-water corrosive environment, but protection can be obtained through plastic covers, preparation of surfaces, or other known techniques.
Launch of a very large vehicle will probably never be kept secret.	Launch secrecy easily obtained. (Note Argus firing from U.S.S. Norton Sound.)
Fairly vulnerable to sabotage.	Isolated and almost invulnerable to sabotage once at sea.
Point supports and stress concentrations on launch pads and during lifting and handling.	Structurally efficient support provided by flotation. Stresses reduced and handling facilitated.
Propellant grain can be exposed to wide temperature variations, causing shrinking, stretching, and possible grain cracking.	Propellant grain remains at or near ambient water temperature which is usually 40° to 70°F, with widest extremes expected of 30° to 80°F.
Spare-parts support is facilitated by means of land transport.	Spare-parts support is more difficult, generally being carried out by air or water transport. It is not too difficult for launches immediately offshore continental U.S., but for remote areas it could be a problem to the same extent as a remote land site.
Recovery of large liquid boosters may be possible, but high firing rates (300 to 400 per year) are necessary to amortize R&D costs of developing large boosters.	Recovery of burned-out boosters not contemplated.
Mobility impossible or difficult to obtain: (a) Fixed concrete pads, at AMR, PMR (b) Railroads (c) Trucks	Basic feature is mobility: (a) Can be launched literally anywhere at sea; includes 70 percent of earth's surface. (b) Could be launched offshore from existing facilities—e.g., AMR, PMR, or any tracking or telemetry station.

support ship could be an electrical umbilical cable, a telemetry link, or even a sonar link.

In order to avoid any moving machinery near the base of the rocket vehicle, it would be desirable to have jet/aerodynamic canard controls near the upper stages. Access could then be gained much more easily since the controls would be above the water line.

Wave-Induced Motions of a Vertically Floating Rocket Vehicle

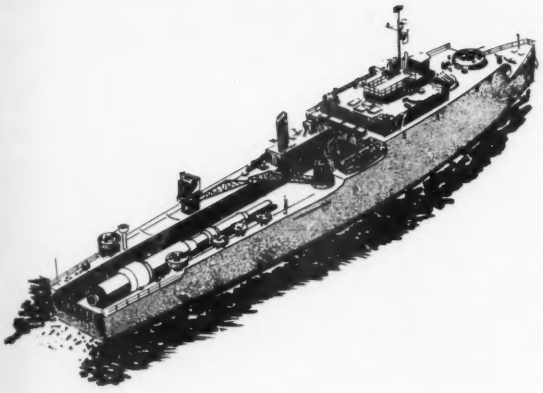
Initial studies of the wave-induced motions of a vertically floating rocket shape assumed trochoidal ocean waves, decaying exponentially with depth. Estimates of angular deviations from the vertical were made, assuming that the upper and lower ends of a rocket followed the circular water particle paths. Two undistorted 1:120 scale models (Fig. 8) of a proposed 175-ft, solid-propellant, three-stage rocket vehicle were tested in a wave tank located at the Naval Civil Engineering Laboratory at Port Hueneme, Calif.[2] This wave tank was 100 ft long, 4 ft high, and 2 ft. wide and used as moving bulkhead wave generator. Predictions of maximum angular deviations from the vertical were made by power spectral methods and showed close agreement with the initial analytical assumptions. Deviations derived were *average*, *significant* (average of highest 1/3), and *highest per 1,000 cycles* (to cover the exceptional case).

The results of the model tests confirmed the excellent stability (Fig. 9). Heaving motion was analyzed in addition to pitching motion, in a similar manner. Heaving motion was found to be less than 50 percent of wave height for deepwater conditions, with a wave period of 13 sec or less. Angular deviations from the vertical under the same conditions were all in the neighborhood of 10 min of arc per foot of wave height (linear).

Open-ocean conditions were investigated at several locations and showed that, on a statistical basis, the ocean does not appear so rough as one might imagine. Fig. 10 shows a cumulative plot of wave heights for various locations. Combining data on pitching motion (deviation from the vertical) with the cumulative plot of wave height occurrences, one obtains a cumulative distribution of maximum angular deviations (Fig. 11). Again, the excellent stability is apparent. For the 175-ft prototype rocket, 50 percent of the time the angular deviation from the vertical is 1/2°, and 80 percent of the time it is less than 1°. For a 40-ft rocket, 50 percent of the time it is 1° or less, and 80 percent of the time it is less than 2°. The above data were derived for a location in the East Equatorial Pacific Ocean.

Mechanism of the Sea Launch

Analytically, the mechanism of the sea launch of a bare rocket is considerably different and more complex than the land launch. Accurate analytical treatment and experimental measurement of the separate effects incident to the sea launch are difficult. Measurement of vehicle acceleration (which is the sum total of the various effects) and analytical comparison with a land-launched equivalent are, however, straightforward. The intention here is



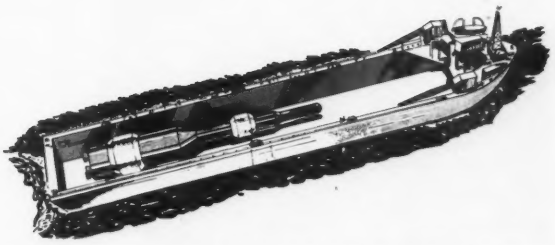


Fig. 5 (left). Saturn-size solid rocket in landing ship dock (LSD).
Fig. 6 (above). Nova-size solid rocket in auxiliary floating dry dock (ARD).

first to discuss some experimental data on a sea-launched rocket vehicle comparing the performance of this vehicle with its land-launched equivalent.

Starting Transient

Consider now the bare—i.e. not encapsulated—rocket vehicle floating in a vertical position. The sea launch begins with underwater ignition and the establishment of supersonic flow of the rocket gases out the nozzle. Underwater ignition presents no problem, provided that the nozzle plug or closure is watertight. To date, 23 tests have been conducted under Project Hydra with no nozzle closure failures. The longest vehicle tested was 105 ft in length, with the bottom of the rocket vehicle (and the nozzle closure) extending 92 ft below the surface of the water. After ignition, the pressure buildup ruptures the nozzle closure. At this point, supersonic flow of the gases out the nozzle is established and maintained, provided that an adequate pressure ratio exists across the nozzle. Under isentropic conditions the required pressure ratio is 1.9 to 1. Under actual conditions the ratio would have to be higher, preferably about 3 to 1. The pressure that the nozzle exhausts to is a function of the depth and the effect of water inertia. The water inertia effect arises as a result of the rocket ejecting mass through the nozzle into the water at a considerable rate. Since the ejected mass and the water cannot both occupy the same place at the same time, the rocket gases tend to displace the water. The water having mass and inertia, tends to remain at rest, and the result is the formation of a high-pressure field in the vicinity of the rocket vehicle having three effects:

(1) Loss in thrust due to increased back pressure. Nozzle choking is a possibility.

(2) A closed breech effect (similar to a mortar shell being fired) which increases vehicle acceleration.

(3) An increased external pressure loading on the rocket vehicle structure.

Salt water hydrostatic pressure is 0.443 psi per foot of depth. Although rockets have been fired underwater previously, the problem here was to launch successfully high thrust, high mass flow rockets without the combination of hydrostatic pressure and water inertia choking the nozzle. Although the limits of "sea launchability" with regard to nozzle choking have not yet been completely explored, tests have been run under Project Hydra (Fig. 12) which have demonstrated successful launching of a single-nozzle rocket having a thrust of 36,000 lbs and a mass flow of 165 lbs/sec, or 10.5 lbs/sec psi of throat area exhausting to a hydrostatic pressure of 40 psi (91 ft depth). This is three times greater than the mass flow of the Scout first-stage booster.

Acceleration Effects

A sea-launched rocket vehicle experiences five acceleration effects unique to the sea launch. These effects, some of which are beneficial, are discussed here.

Buoyant Effect

A rocket vehicle launched from a vertical floating position has a starting acceleration which is 1g greater than its equivalent land-launched rocket as a result of the buoyant force:

Sea launch

$$\begin{cases} \Sigma F = T - D - W + F_{\text{buoyant}} \\ \text{initially } F_{\text{buoyant}} = W \text{ and } D = 0 \\ a = (\Sigma F/W)\, g = (T/W)g \end{cases}$$

Land launch

$$\begin{cases} \Sigma F = T - D - W \\ \text{initially } D = 0 \\ a = (\Sigma F/W)\, g = [(T - W)/W]\, g = \\ \qquad [(T/W) - 1]g \end{cases}$$

The sea-launched rocket in prelaunched position is something akin to a land-launched rocket resting on a compressed spring.

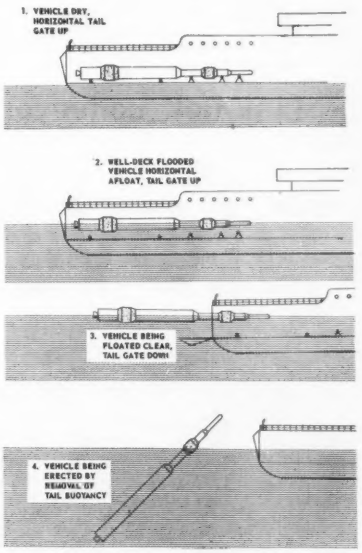

1. VEHICLE DRY, HORIZONTAL TAIL GATE UP
2. WELL-DECK FLOODED VEHICLE HORIZONTAL AFLOAT, TAIL GATE UP
3. VEHICLE BEING FLOATED CLEAR, TAIL GATE DOWN
4. VEHICLE BEING ERECTED BY REMOVAL OF TAIL BUOYANCY

Fig. 7. Undocking and erection to the vertical from a landing ship dock (LSD).

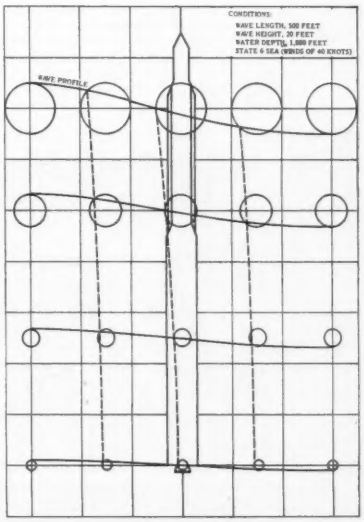
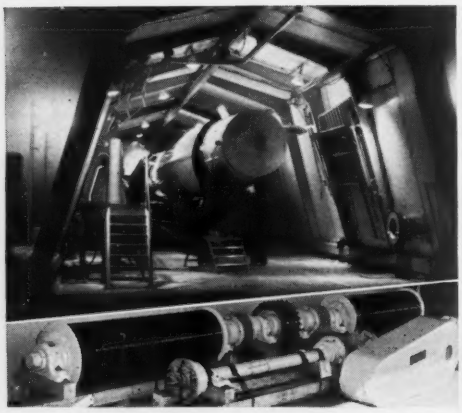


Fig. 8. Wave profile of trochoidal ocean wave showing wave decay with increasing depth.



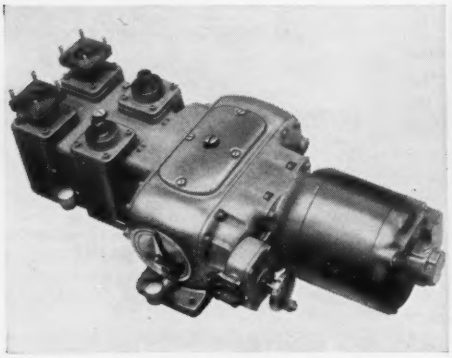
Protecting the protector. A Link-Belt drive assembly—roller chain, sprockets, geared flexible couplings, and spherical roller bearings—is standard equipment for retracting the shelter prior to launching the Douglas Thor IRBM Missile.

Link-Belt roller chains are used for tensile loading, as compression chains, and as drives in missile handling, positioning and launching. They are also used extensively on ground-support equipment.

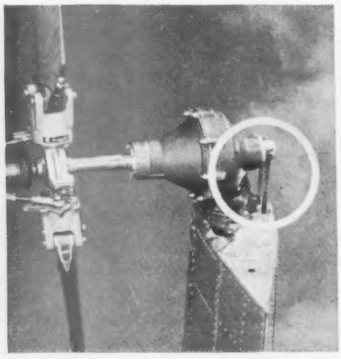
New baggage-handling system introduced by United Air Lines at San Francisco International Airport. System has 3,300-ft. Link-Belt belt conveyor. Belt speeds range up to 363 fpm. System can sort 32 bags per minute.

Link-Belt conveyor and mechanical power transmission components..

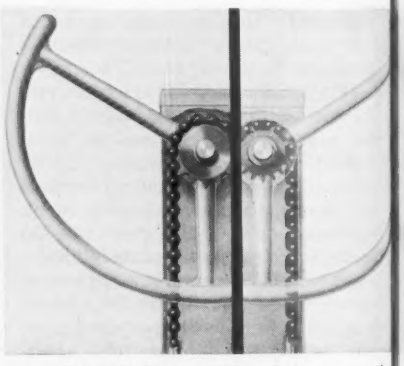
proved where only



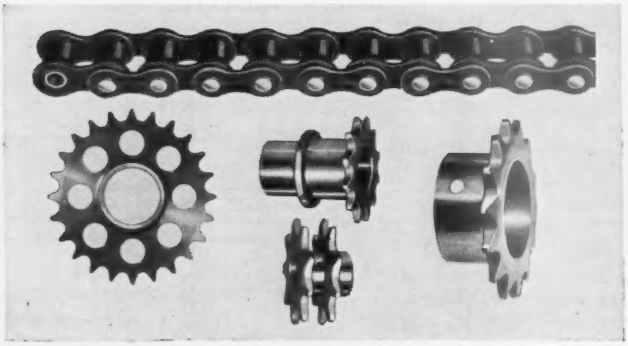
Link-Belt aircraft tachometer test drive—a sturdy, self-contained unit for a wide range of test requirements. Basic transmission is motorized Variable Roller Drive with 10-to-1 infinite output speed range.



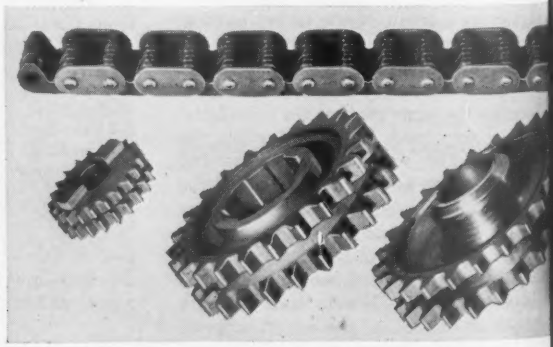
Link-Belt silent chain is used for tail rotor pitch control on this HU-1 model Bell helicopter. Link-Belt was chosen for its strength, lightweight, no-backlash operation.



Link-Belt silent or roller chains are used on aircraft controls. Silent chain eliminates chordal action, minimizes frictional loads. Roller chain has high strength-to-weight ratio, withstands severe shocks.

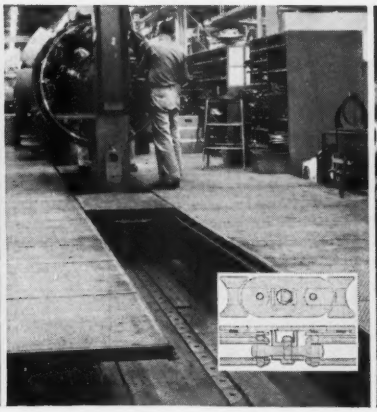


Link-Belt roller chains and sprockets. High strength, light weight, precision built in a complete range of types and sizes . . . in steel, stainless steel or cadmium plated to meet design requirements. Standard A.S.A. tooth form assures a correct fit between chain and sprocket.



Link-Belt silent chains and sprockets. Available in a wide variety of sizes and types with sprockets of almost any construction . . . steel or stainless steel . . . to fit government specifications. All have minimum weight, high tensile strength.

Two Link-Belt parallel shaft speed reducers are used at T.W.A.'s overhaul base to test aircraft cabin compressors. The two speed reducers enable one prime mover to be used to test two different types of aircraft engine cabin compressors requiring different speeds.



Aircraft engines at T.W.A.'s Kansas City overhaul base are carried from tear-down to final assembly on Link-Belt in-the-floor conveyors. Conveyor speeds can be varied from 2½ to 35 ft. per hour.

Airplane wash rack at United Air Lines, San Francisco International Airport, speeds and simplifies washing job with 380 ft. long Link-Belt in-the-floor chain conveyor, towing three planes at one time.

y the best will do

Rigid aero/space tests have proved the value of standardizing on Link-Belt equipment for a wide variety of handling, maintenance and operational applications

Link-Belt equipment is built to the highest standards with components correctly integrated for smooth-working efficiency. All this is backed by Link-Belt's complete research, engineering, manufacturing, warehousing, erection and service facilities. Call or write your nearest Link-Belt office for data.

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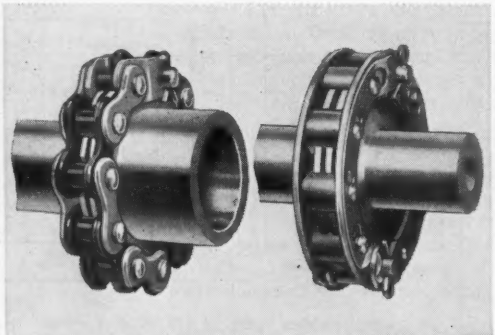
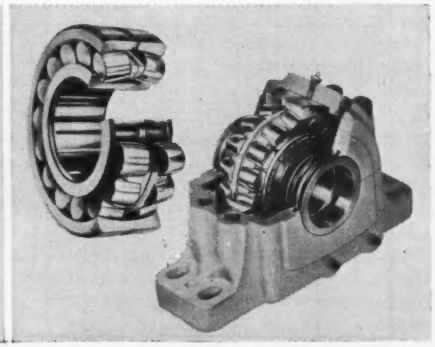
ink-Belt leaf chains. Chains com-ine great strength and light weight. sed as balance, counterweight nd sling chains. All parts hardened or maximum durability.



Link-Belt flexible ring-type couplings (right) and flexible roller chain couplings (left) are widely used for joining wing flap sections. They have minimum backlash, can accept up to 5° total angular misalignment.



Shafts turn smoothly with Link-Belt self-aligning spherical roller bearings, spherical roller bearing pillow blocks, and self-aligning ball and roller bearings in pillow blocks, flanged, flanged-cartridge, cartridge and takeup blocks.

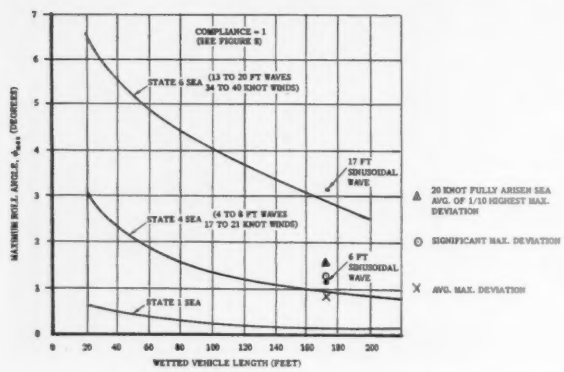


Fig. 9. Maximum roll angle (ϕ_{max}) vs. wetted length of vehicle for various sea states.

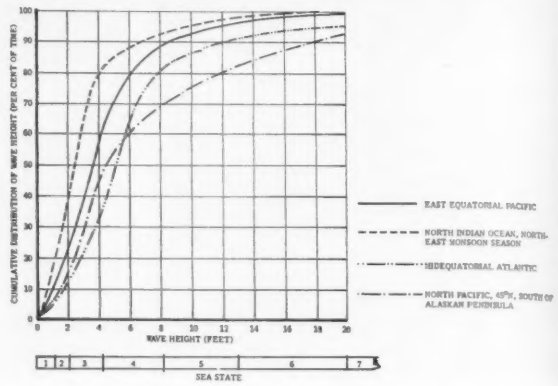


Fig. 10. Cumulative distribution of wave height occurrence for various locations.

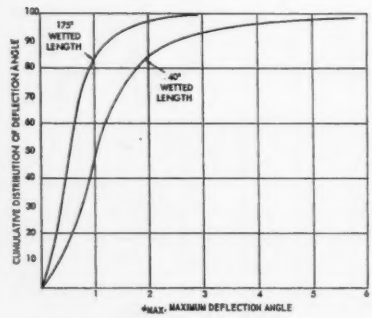


Fig. 11. Cumulative distribution of maximum angular deflection from the vertical for 40- and 175-ft vertically floating cylinders, East Equatorial Pacific.

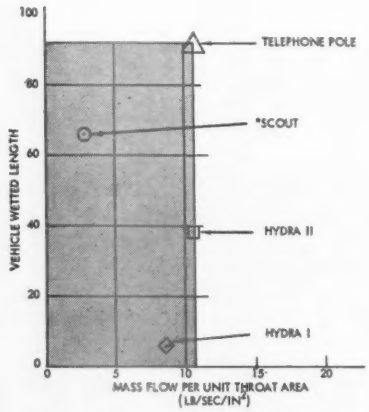


Fig. 12. Shaded area indicates the regime investigated in which there was no water inertia effect which resulted in nozzle choking. (* Scout has not been water launched; included for comparison only.)

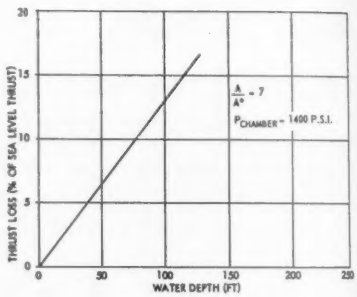


Fig. 13. Thrust loss as a function of water depth.

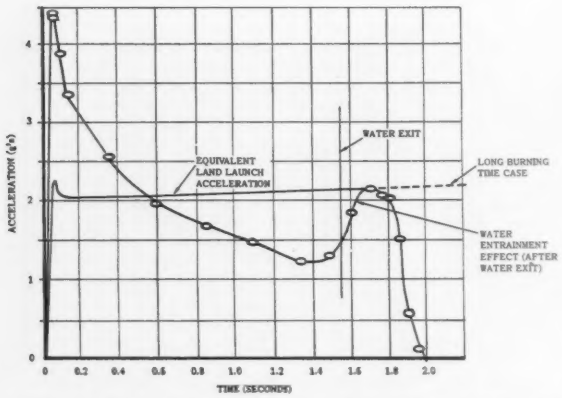


Fig. 14. Acceleration vs. time for Project Hydra telephone pole test at NMC on June 3, 1960.

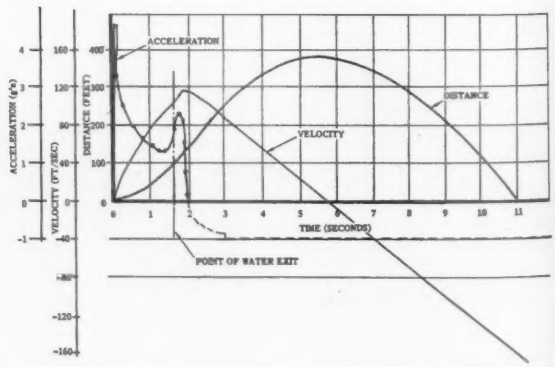


Fig. 15. Acceleration, velocity, and distance vs. time for Project Hydra telephone pole test at NMC on June 3, 1960.

Water Entrainment

As a result of its motion through the water, the sea-launched rocket entrains an amount of water. The effect appears as an increase in the mass which must be accelerated by the rocket.

Thrust Loss

Sea-launched rocket vehicles have a thrust loss resulting from the nozzle exhausting to hydrostatic pressure. Fig. 13 shows the thrust loss in percent of sea-level thrust as a function of water depth for a rocket used in Project Hydra. For the sea launch, as for any rocket designed to operate in a region of considerable ambient pressure, the most efficient rocket is one with a high operating chamber pressure.

Water Drag

Although the vehicle velocity during the sea-launch phase is small relative to the velocity attained later in flight, movement through the relatively dense (in comparison to air) water medium can result in a discernible loss, depending upon the vehicle configuration. An optimum configuration to minimize water drag would be a vehicle with a smooth external surface of constant diameter in order to reduce parasite and pressure drag.

Water Inertia Effect

The effect of water inertia produces a pressure field about the rocket vehicle which tends to choke the nozzle as described above in conjunction with the starting transient. Two other effects are, first, that the increased pressure can be deterimental to the vehicle structure and, second, that the closed breech effect increases the launch acceleration.

Fig. 14 is a plot of acceleration vs. time for a telephone pole which was launched from a vertical floating position using a short burning time booster. During the initial portion of the launch phase, the sea-launched vehicle experiences a greater acceleration than a corresponding land-launched rocket; during the latter portion the reverse is true. A comparison between the sea launch and land launch can be made by comparing the area under respective acceleration vs. time curves during the launch phase. In this particular case, the sea launch is 4.4 percent less efficient, in large degree because of the high drag of the telephone pole. It should be remembered that the gain or loss refers only to the launch phase and not to the entire burning phase. Thus, for a sea-launched booster with a burning time of 40 sec, the in-water phase would be a very small part of the overall burning time. After water exit, a sharp increase in acceleration is noted. The reason for this increase is that during launch a certain amount of water is entrained by the vehicle and the water adheres to the vehicle at water exit. Shortly after exit, as the water is shed, the overall mass is reduced and, under constant thrust, an increase in acceleration results. Analysis of the portion of the curve after water exit indicates that 2,370 lbs of water were shed in the first two tenths of a second after exit. This is equal in weight to a water layer of one-inch average thickness. Fig. 15 shows the acceleration and derived velocity and position vs. time curves for the telephone pole launch test.

References

[1] Draim, J. E., and Stalzer, C. E., *Sea Launch of Large Solid Propellant Rocket Vehicles*, Papers Volume of XIth International Astronautical Congress, Stockholm, Sweden, Aug. 1960.

[2] Leendertse, J. J., *Wave Induced Motions of a Rocket Vehicle Drifting in a Vertical Attitude*, USNCEL, Port Hueneme, Calif., Aug. 5, 1960.

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Decentralized Decisions (Continued from page 15)

Polaris, Atlas, and Bomarc, the relationships among the scattered corporate and governmental organizations in development, proof, production, and follow-up support may be described by a network.

A network is essentially an outline of events and the activities that lead to each. Before the work starts, a proposed network shows a starting point, a completion point, and initial work routes between them. A network starts with specifying the originating source of authority, the ultimate objective, milestones (in level of detail to be discussed below) of accomplishments, and decision points along the activity paths. Thus, a network is a product-oriented description of past and future activities, with major events as milestones against which progress may be measured, and with other major events shown as decision points.

In describing networks, the terms *milestone*, *activity*, and *decision point* are essential. Event milestones, as objectively measurable accomplishments, have a long history of use in industrial management; work activities are also familiar. The Air Force and the Navy have introduced these terms into their contract procedures. An unpublished Air Force document[6] dealing with weapon system contract administration explains the terms:

> An event is a milestone representing the point in time at which an activity is started or completed. Events that might bound an activity are, for example: 'component X received' and 'component X testing completed.'
>
> An activity is described as: " . . . a job or task in the weapon system development, requiring both time and resources. Activities represent the work that must be done to achieve the program objectives. An example of an activity is 'test component X.' "

An earlier Navy document[7] sets forth the same concepts in slightly different language:

> A milestone is ". . . a meaningful specified accomplishment in the development program. An event should be recognizable as a particular instant in time." "An event is separated from other events by activities. An activity is a time-consuming element in the development process. It is represented on a flow chart (or network, Ed. note) by an arrow. An activity cannot be started until its preceding event has been accomplished. A succeeding event to an activity cannot be accomplished until the activity is completed."

Decision points, as related to the management of weapon system programs and as displayed in networks, are discussed in subsequent paragraphs.

Delegations

The first evidence of management in a program is a series of initial decisions, from the office of the responsible program manager; these are called *delegation decisions* because they delegate authority, responsibility, and funds to others for performing specific parts of the work. The basic structure for program management may be traced from the program manager's office, through successive tiers of organization, to the most remote working groups—by continuing delegations. These delegations are the process by which management partitions the work. The program manager may assign work to subordinate units within his organization, to sister units within the larger organization of which he is a part, or by contract to other organizations, governmental or

private. His ultimate responsibility and authority are undiminished by his acts of delegation to other organizations. The network of events and activities, reflecting the delegation decisions, leads from the program manager's office into each of the other units made responsible for parts of the program; his responsibility is not discharged until the delivery of the product at the end of the network.

In organizational terms, the basic network records these levels of delegation decisions, showing each instance in which any one organization has an input or an output to some other organizational unit. The critical points* for each subunit are the start and the completion of its activities, with intermediate inputs and outputs—if any—identified between these two points. In this situation the subunit may have a network of its own which delineates the activities and events it determines to be necessary to completion of its assignment. This network of the suborganization may in turn encompass additional suborganizations, in which case the networks are said to be *nested*.

Alternative Paths in Development Programs

Describing delegation decisions and nested networks may give the erroneous impression that objectives are necessarily reached by a predetermined route. It should need no reiteration that the essence of development programs is the search for a way through the unknown to a desired result. That is, whether there is a unique solution or whether there are alternative ways of accomplishing the same result, a program is conceived and a network of activities and events established before all of the specific routes to success are determined. "Any complex development project must be undertaken in steps or stages, the later stages depending upon the results of the earlier ones. It is therefore a problem in sequential decision making."[8]

There are at least two classes of situations requiring consideration of alternative methods for accomplishing the same objective. In one case there may be a unique physical situation and a unique physical solution. In such a case it may be prudent to consider giving parallel technical assignments to more than one organization to reduce the uncertainties of success. In the other case, ranges of physical solutions may involve compromises among cost, time, or performance. With no one best solution really available, the choice among alternatives rests on a judgment as to which compromise among cost, time, and performance produces the most desirable solution.

The existence of alternative routes through the unknown has a different significance for the organization unit responsible for one specific solution, in contrast to higher organizational units whose larger responsibilities include broader solutions of which the first unit's part is but one piece. To the immediately responsible unit, finding an acceptable solution is its primary concern, within the limits of time, cost, and reliability set for it by higher units. Its knowledge about physical phenomena, the properties of materials, relative costs and reliability, and skill and intuition are brought to bear in considering various internal alternatives, testing each, rejecting some, and eventually eliminating all but one route to the assigned objective. Its skill in this process is, fundamentally, the reason it was assigned the responsibility for this specific piece of work by the program manager.

To the higher echelon, the intricacies of the lower organizational unit's selective processes are of minor concern. The unit was initially selected for the task on the basis of demonstrated or presumed capability for this task and, of equal significance, because the unit committed itself to finding an acceptable solution within definite limits of cost, time, and reliability. Accordingly, to the higher echelon, the significant facts are whether or not the lower organizational unit continues to agree to its performance commitment and the degree of assurance which can be assigned to prediction of its success.

Reducing Uncertainty Through Redundancy

The pursuit of a known, or desired, objective through the unknown is of course fraught with uncertainty. Where effort is being devoted to the search, uncertainty cannot be reduced by tighter restrictions on the searcher, by frequent reviews of his failures, or by demanding more detailed justifications of what he plans to do in the immediate future. Such methods presume that the unknown is not really unknown and that information exists indicating which is the "right" way to proceed.

Uncertainty can be reduced, though never eliminated, by recognition that while current information does not show a "right" path to the desired end, informed hunches show promising courses worthy of investigation. Pursuit of any one of the alternatives is expensive; pursuit of two or more obviously adds to the expense. However, it is likely that increased costs can buy decreased uncertainty.

The physical "redundancy" in electronic circuits is comparable. In certain advanced electronic gear, the reliabilities of the parts, when assembled into a "black box," produce an overall reliability that may well be below the acceptable limit. Increasing the reliability of the completed black box (analogous to decreasing the uncertainty of success facing the program manager) may be achieved in spite of the current state of the art and unreliability of the circuit elements, through redundancy in design. With redundant circuits, when a critical circuit fails, failure of the system is avoided by the stand-by circuitry which operates in the event of a first failure. In spite of uncertainty of the failure rate of the paths through the black box, the reliability of the whole is raised by providing alternative paths to meet the operating requirements. Similarly in managing an R&D effort with uncertainty about any one path through the unknown, the certainty of success can be increased by increasing the number of paths along which effort is expended. The redundancy may be in terms of additional organizational units pursuing identical physical approaches or in terms of differing technological approaches to the same objective. The trade-off between economy and certainty is obvious. Not so obvious, but equally important, is the burden placed upon the information system.

The manager must be provided sufficient information to be assured that each different approach to the objective is in fact a chosen approach by responsible management. In addition, "stop-loss" decision points must be firmly established along each route, so that as soon as any one of the alternative routes shows a sufficient probability of success, other alternatives will be terminated, or deliberately continued for objectives other than the original one.

Milestone Events vs. Decision Points

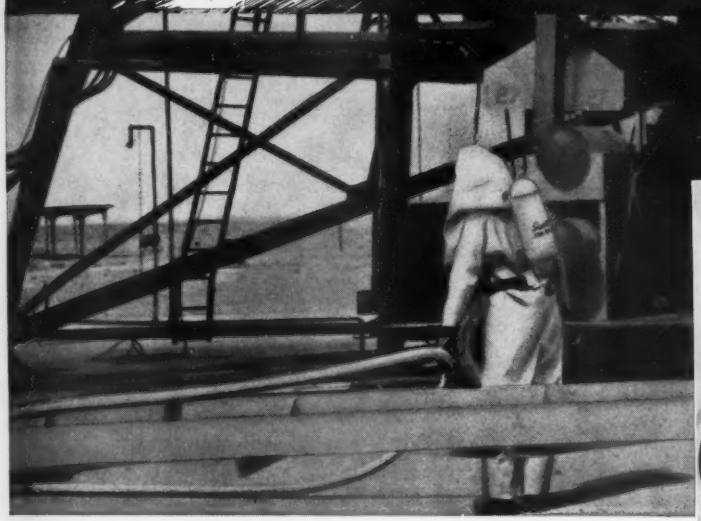
The accomplishment of milestone events, or their slippage, measures technical progress toward achieving the end product. The action taken at decision points, or the lack of it, is a measure of the performance of management in the program.

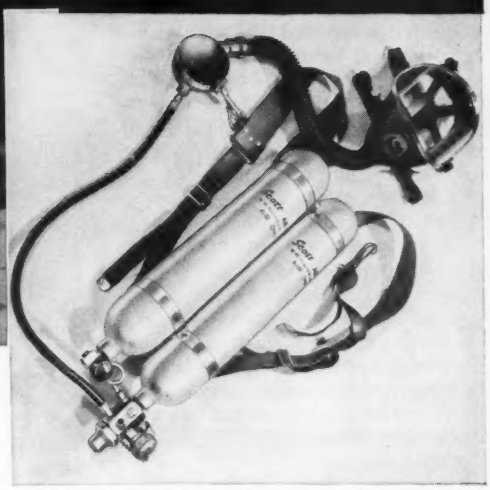
There are several kinds of decision points which will be discussed in relation to various levels within the program organization. Management decisions are required at every level to resolve ambiguities and lay out specific work assignments. Management decisions are also involved between organization levels, when a higher level has limited the delegation of authority and responsibility to subordinate organizations by specific constraints, which can only be removed by future decisions from the

* Decision points are also critical and belong in the same analysis, but for ease in composition they are treated separately in sections following.

Scott AIR-PAK

as much a part of the Weapons System as the Rocket





Fueling is one of the most important operations in the successful launching of a rocket. Since propellants are poisonous, breathing protection equipment must be worn. The Scott Air-Pak Model 8100-A2 has been designed to meet the exacting requirements of this hazardous operation. It delivers pure, fresh air, instantaneously "on demand" as required by the wearer regardless of the degree of exertion.

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The Scott Air-Pak has been established as standard equipment by Army Chemical Corps and Army Ordnance for launching crew protection.

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higher level. The subordinate units are not allowed to proceed with the work beyond such a point, if the delegating organization does not make the required enabling decision. A third kind of decision point exists outside of the program structure, where favorable decisions are required at each management review to continue the program as scheduled.

Decision Points for Resolving Program Ambiguities

Networks are drawn up in the present, describing the past, and stretching into the future. In any research and developmental program, however sharply defined the objective may be, the intervening steps are inherently "unknown." As previously stated by the authors,[9] "The lack of information between the beginning and end of a program is normal and to be expected. Part of the lack of specific information (the 'unknowns' just referred to) is due to the absence of knowledge which will be obtained as the work progresses, and part of it is due to inability to predict details of work not yet done." However, to reach the objective, these unknowns must be resolved. The points at which it is expected that required information will be available are identified as "decision points," points calling for specific management action to direct or redirect the immediate course of work to reach milestones further in the future. In management terms, a path through the unknown is charted step-by-step as facts become available. As these steps are scheduled, they can be plotted on the network as "decision points." The action when taken is a decision, measurable as an event essential to progress. Although a decision may, in retrospect, be evaluated as to its effectiveness, decision points need not be confused with milestone events, which directly involve the product's physical evolution.

These points of decision for step-by-step resolution are set by a responsible official for his own guidance and that of his organization. They reflect his relationship with his own "in-house" work centers. Such decision points cannot be set for periods far into the future; they are established progressively for definite future dates as rapidly as technical work progresses and sufficient additional knowledge is acquired. A decision identified by one of these points may involve more than "in-house" work for the immediate future. This occurs when it is decided to delegate a part of the newly scheduled work activities to an outside organization. In either event, as rapidly as decisions are reached and communicated to other affected organizations, additional parts of the network can be drawn in sharper detail, charting more of the course through the unknown in terms of new milestone events, work activities, new decision points, incremental funding commitments, and performance-reliability specifications.

Decision Points Between Organizations

The second type of decision point involves two different organizations. When organization A has delegated to organization B a defined activity with a specified starting point, committed resources, and defined objective, the delegation may leave with organization A the right to approve, disapprove, or modify some intermediate step before it may be taken by organization B. To organization B, the network shows a decision point beyond which the organization cannot proceed until authorization or instruction has been received from organization A. To organization A, the network shows the same decision point and possibly the earlier date by which a proposal from B or other specific information must be received to provide the basis for the scheduled decision.

These decision points occur frequently in the relations of a government agency with its industrial contractors. Incremental funding is an obvious example. The contractor cannot proceed, no matter how clear the course of the technical activities may be, until the contracting government agency has issued the paper committing the next increment of funds. The right to "review and approve" drawings and related contractor products is another example. Corporate weapon system managers often reserve similar rights in their subcontracts with other industrial firms (Fig. 2).

In far-flung weapon system teams where the contracting chain may be three or four tiers deep, there is serious danger that the effect of these decision points may not appear on all of the networks that may be involved. Thus, when organization A retains a right to approve of the drawings of organization B, it may be that some of the drawings have been further delegated to organization C, pursuant to subcontract terms with organization B. The network of organization C should reflect the situation, namely, that their drawings require the approval of organization B, a decision point on both B and C networks, and that in turn B's approval is subject to authorization from A. This "layering" is a fact of life in the systems business, a fact too seldom reflected in the information B supplies to C.

Decision Points Outside the Program

The two types of decision points just discussed properly appear as events on each organization's network. A third type, often of greater significance, is not so readily identified and may never appear on a network. Decisions to modify drastically or even to terminate a program may come from causes far beyond the scope of the program. Thus, in the course of the annual budget exercise in Government, changes in requirements or the emergence of a different program, perhaps more promising, may lead to cancelling an on-going program. A contingency always hanging over a weapon system manager is the necessity at any time to defend the very life of his program. The information basis for program defense would lead too far afield for discussion here, but the type of decisions involved cannot be ignored, regardless of the contingent nature of such a "decision point."

Other conditions place additional responsibilities on subordinate management's control of delegated tasks. One is the cumulative result of higher management's commitment of money and calendar time to the subordinate unit. Neither can be salvaged once spent. Because of these commitments, higher management has a vested interest in the successful performance of delegated tasks. Accordingly, subordinate management is obligated to inform higher management when successful performance appears endangered by inadequate progress. Proposals for change or requests for assistance should be made by subordinate management in these situations. Higher management must maintain measures of the progress actually made by organizations responsible for delegated tasks. One use of such measures of progress is a continuing appraisal and justification for not revoking a delegation.

The other condition is the contingency that external factors such as delayed availability of inputs or changes in requirements may trigger a re-evaluation of performance possibilities. New circumstances invalidate the assumptions on which the original commitments rested, redirection requires higher management decision following joint consideration of the circumstances. Subordinate management is responsible for proposing revised time factors, reliability levels of product performance, and costs to be expressed in a new delegation, commitment, and work specification. The decision to be made is one of trading among these factors. Each of these three types of contingent decisions are difficult to schedule and display, in advance, on a network. However, once the contingency has arisen and decision is scheduled or made, these facts belong on the network display. As a matter of record, these facts are crucial for subsequent studies.

Reporting Criteria

Criteria for selecting levels of detail

AiResearch pressure suit cooling unit

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This portable, lightweight package keeps the pilot cool and comfortable on the ground in his flight pressure suit from one to two hours. Utilizing cryogenic liquid oxygen as the coolant, it requires no electric power or other connecting supplies which might hinder the pilot's mobility.

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to be recorded by each participating organization and for selecting information to be transmitted to other organizations may be derived from program managers' decisions, the substance of delegations (specification of time, cost, and performance-reliability), and decision points. Thus, starting at the lowest echelon where all of the activities and events in the network except the first and the last are "in-house" and under the control of the same supervisor, only the start and completion are reported to other organizations in the program.* The report on starts is made to the organization whose input initiates the activity, the report on completions is made to each organization to which the outputs are sent. In addition, the report of either start or completion may be sent to higher echelons. The criterion for selecting what to report is applied each time one organization has an input from or an output to another organization. For each milestone involving two or more organizations, each reports on what crosses the interface. An interface is the linkage between separate organizations, participating in a common program, providing for communicating program directions. Examples of interface flow are the information or product output of one organization becoming the input of another, and the decisions of one organization in the program constraining another. The full detail of each network is retained by the immediately responsible organization. These details are, of course, available for special study to higher organizational units on a "management by exception" basis.

The same criterion may be applied to decision points. Decisions whose significance pertains solely to "in-house" activities need not be reported to others. However, where a decision point reflects a constraint between two organizations, the networks and the reports of both organizations involved identify such decision points. This criterion of selection of what to report, rather than what not to report, is particularly relevant for decisions where an organization has retained the right to approve or disapprove of the work and proposals of another organization.

The details of activities and events within a task are relevant only to the immediately responsible organization. Reporting to other echelons can be confined to interfaces of decisions and inputs from and outputs to others without depriving other echelons of the information they need repetitively.

This distinction between details of significance solely to an immediately responsible organization, while totals or cumulative effects are of relevance to others in the program, particularly higher echelons, pertains from the lowest level of any development program up to and beyond the top office. Consider, for example, the top office responsible for a weapon system. To this office, the critical knowledge needed about each immediately subordinate participant is the basic dates of needed inputs and decisions and committed outputs, with costs, performance magnitudes and assurances to be assigned to predictions of success. However, to those in the departments over such a weapon system office, each actual or potential weapon system is, in itself, only one alternative among many possible means to a desired end. When these alternatives are weighed, the weapon system program manager is required to report for his weapon system the cost, time, performance, and predictions as to eventual levels of each in terms comparable with similar magnitudes for competing programs.

From another point of view, these criteria are eminently practical. A pervasive fact of American corporations is the heterogeneity of internal procedures, accounting methods, and bookkeeping practices. The industrial complexes pulled together for developing a weapon system embrace companies whose ways of doing business are fiercely individual. Whatever the internal differences may be, at the point at which any organization accepts a delegation and makes a commitment to accomplish a part of the weapon system development, the specifications of the commitment are, of necessity, in terms understandable to participants in the program. Reporting which follows the substance of decisions and delegations makes it possible to achieve necessary uniformity without individual participants changing their internal systems, leaving each company free to operate its "in-house" activities in its own terms. This is a reflection, in terms of reports and information, that the details of activities and events within a task are relevant only to the immediately responsible organization.

This description is one of paper-and-pencil manual reporting. If computers are involved, as they currently are in a number of governmental and corporate systems, the actual flow of data may be direct to a computer center. This direct reporting does not change the principles set forth. Read-outs supplied to the various organizations are held to the same level of detail as those spelled out for manual reporting.

Recapitulation

The relationships among organization units of input/output provide the basis for measuring progress of the whole program and its parts in terms of technical, physical accomplishment. Such relationships are established by delegations of specific tasks and are set forth in greater detail as the time is approached for performance by the units involved. The delegations of detailed tasks for the whole program cannot be made firm, in the beginning; delegations are sequentially made by management in step-by-step definition of tasks and assignments to organization units. The information system is continuously responsible for displaying, through the networks and back-up data, the input/output and decision interrelationships as they are developed.

Each new delegation throughout the course of the program is a result of management decision. In this process, additional decision points in the future are established as points at which affirmative action by the delegator will be required to permit the subordinate group to proceed further.

In the relationships among organization units through which management operates, each unit that delegates a task is concerned repetitively only with information of the interfaces of its subordinate units, including decision points. Each subordinate level is responsible for maintaining the details of its own internal network of activities, milestones, and decision points. Network displays of each such unit reflect these differences. Decision points between the beginning and end of delegated tasks, whether disclosed and scheduled in advance or not, provide higher management re-entry into the details of delegated tasks. The substance of decisions reached at scheduled decision points and upon occurrence of unscheduled contingencies are displayed in the networks of both organizations. In addition to showing newly scheduled and more detailed activities, revised milestones, and new decision points, the network should also show for historical purposes the time when the decision was taken.

Conclusion

Emphasis upon drafting networks of activities and events brings management and its delegation of responsibility and authority into sharp focus. Emphasis upon including decision points in the network calls for a degree of openness rarely found in today's economy, particularly in the government agencies' contractual relationships with weapon system corporate managers and their industrial teams.

As rapidly as management uses networks, and has the courage to identify each restriction it wishes to impose upon its suppliers, the information system can be tailored to the process. Criteria are provided for assurance that the necessary transactions are observed, meas-

* These reports include the interrelated items of time, cost, and performance and reliability; the full scale of these reports is shortened for ease in exposition in the following paragraphs.

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ured, and recorded, and that only the minimum necessary data are transmitted. A criterion is provided for establishing this minimum. At the same time, program visibility is maintained so that responsible management can see potential troubles as they develop anywhere in the team and have the information necessary for remedial action. A basis is provided for management by exception. Information on program performance will exist at every level or organization for ex post facto review of all transactions as a basis for rewarding rationally, not fortuitously, those who find a way through the unknown.

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Aircraft Support Equipment at Sea (Continued from page 19)

selection of support equipment. While these criteria may be considered "basic" to any equipment selection, ashore or afloat, experience has shown that they are frequently ignored or even misunderstood by many support system designers. Many additional criteria such as human adaptability, mobility, and quality are also applicable to the design of support equipment, however, the scope of this paper precludes their discussion.

Universality

The Fleet commands have long been concerned with congestion on the flight and hangar decks, commonly called "clutter," caused in part by the large quantities of support equipment required. They have envisioned the development of a completely universal support system to provide for the basic servicing requirements of the aircraft and also reduce the quantities of equipment presently required. An approach to this goal, but not necessarily a final solution, has been the development of the model MD-3 multipurpose tractor. This concept, which has received considerable attention, assumes that most of the aircraft maintenance services required on the flight deck can be provided in a single vehicle. These services include air conditioning, low-pressure pneumatic power, electrical power, and towing capability. In consideration of this requirement, the adaptability of a gas turbine as the prime mover was recognized. Aircraft starting can be provided pneumatically by the use of bleed air; electric power, both d.c. and 400-cycle a.c., is provided by means of shaft-driven generators, and air conditioning is supplied by utilizing the principles of air cycle refrigeration. The relatively small size of this servicing package, which is attached to the rear of the MD-3 towing vehicle, attests to the success of this design approach (Fig. 2). Note that the overall height of the vehicle has been limited to 36 in. which allows passage under aircraft while in use on the deck. Since modern aircraft such as F4H, A2F, and A3J require the simultaneous use of conditioned air and electrical power when avionics equipment is operated prior to flight, the ability of this package to provide these services simultaneously aids in the overall reduction of deck clutter. Prior to the use of this equipment, four individual power units were required. It should be noted that, as an alternate to the design of this multipurpose vehicle, consideration was given to the utilization of deck edge power (services supplied from ship to the edge of the flight deck). This approach was not pursued because of the problems associated with the myriad of servicing lines which would cover the deck spaces and restrict the movement of aircraft.

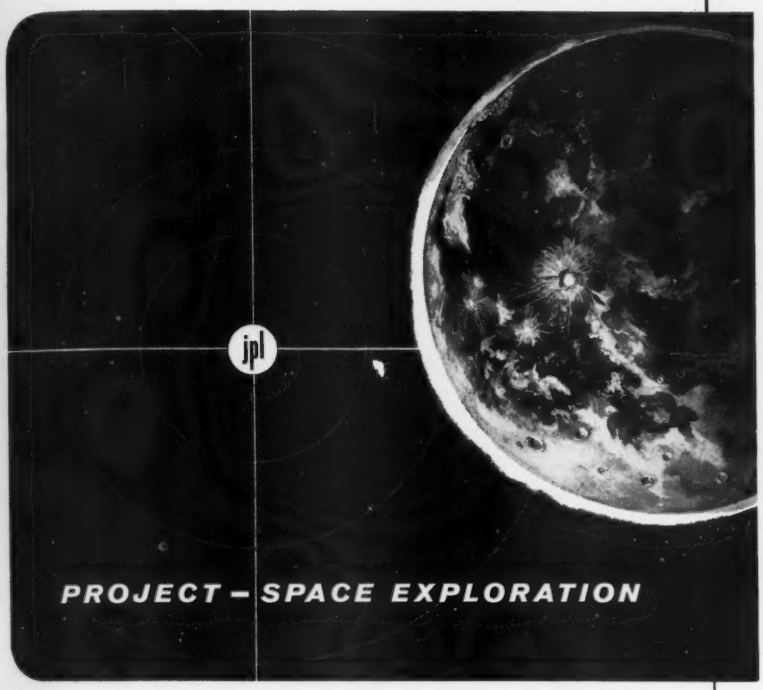
Reliability

The MD-3 power generation system noted above must provide a high degree of reliability. Interruption of power during the mandatory warmup period of the airborne navigation system adversely affects its alignment, and scheduled launching may be delayed if additional stabilization time is required. Cost, and limited storage space available, limit the practicability of achieving reliability by redundancy of either complete systems or circuits.

Simplicity

The introduction of aircraft with complex electronic systems has created maintenance problems which are often

Fig. 2. Model MD-3 low-profile tractor servicing the A3J "Vigilante" aircraft.



In the next decade, the United States is committed to an extensive program of space exploration. The Jet Propulsion Laboratory has been assigned, by the National Aeronautics and Space Administration, a responsibility for lunar, planetary and interplanetary un-manned exploration programs.

In the field of planetary exploration, the development and technology of automatic spacecraft and the gathering of scientific knowledge concerning the planets and their environment is involved.

By 1970, sufficient scientific data is to be acquired demonstrating the feasibility of spacecraft capable of orbiting and landing on Mars and Venus. In addition, programs will be initiated for probing Mercury and Jupiter and for further penetration into space.

The early Venus and Mars missions will utilize the Centaur launch vehicle and will constitute the "Mariner" series. These will be followed by the "Voyager" series employing the Saturn system.

The vast amount of information to be acquired, the scientific research and testing necessary, the new concepts to be investigated and the number of areas to be explored constitute an extensive long-range program. The challenge of probing the unknown, the vigor with which these problems are now being attacked and the demonstrated stability of the whole JPL operation provide career incentives for engineers and scientists in every field.

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•

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•

Work with research engineers and scientists as support instrumentation for studies on materials for rocket motors, space vehicles and space experiments—scope includes crystalline metallurgy, high temperature stress-strain measurements, induction and resistance heating.

•

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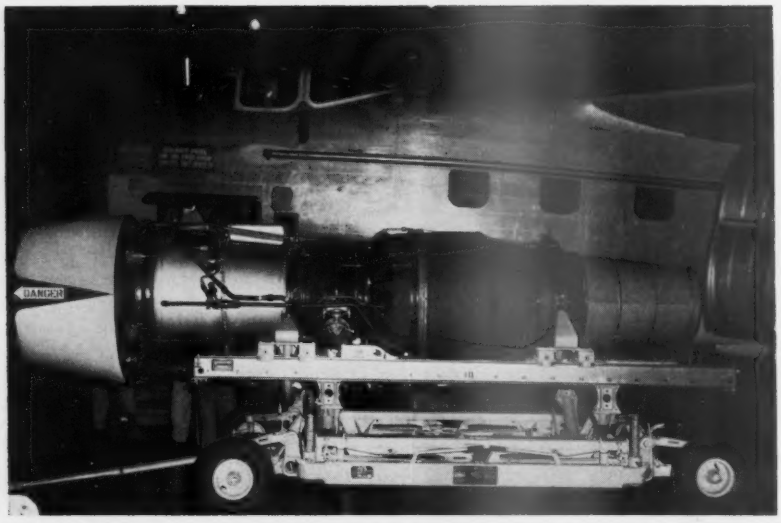

Fig. 3. Engine installation and removal trailer used to remove the J57 engine from the A3D aircraft.

beyond the ability of the average technician to diagnose without complex test equipment. It is in the design of test equipment that the paradox of simplicity becomes apparent. It is recognized that equipment can be designed which will automatically analyze the performance of the system and indicate not only the malfunctioning component but also the optimum corrective action. While simplicity of operation can be achieved with this system, the services of a skilled technician are often necessary to maintain the test equipment. An example of a system of this type is the BACE (Basic Automatic Check-Out Equipment) which is being incorporated as an integral part of the A3J and W2F avionics systems. Obviously, the immediate area in which the skill is required has merely been transferred and the basic problem of simplicity has not been solved. It is recognized that a blanket decision cannot be made in this area, and each design must be weighed on its own merits. It has been found that in most cases it will be necessary to select automatic test equipment to "speed" the diagnosis of a malfunctioning system in order to ensure the availability of aircraft for flight. Therefore, it must be concluded that the definition of the term "simplicity" in equipment design must be a case of individual judgment, depending upon which factor is of prime importance—simplicity of design or simplicity of operation. While it is recognized that neither factor should be compromised, unavoidable personnel transfers and the necessity for rapid mobilization require that operational simplicity be emphasized if aircraft readiness is to be maintained.

Fig. 4. The F4H aircraft with some of its standard and special support equipment.

Standardization

The complexity and cost of any support system, whether ashore or afloat, dictate that standardization efforts be expended to ensure that the equipment provided is the minimum number required. One area in which notable progress has been achieved is in the field of engine handling. Conventional systems for handling engines have proved to be inadequate for carrier operations. The congestion of working spaces, delicacy of equipment, and engine weights of approximately 10,000 lbs necessitated the development of new equipment to simplify operations and reduce the number of units required. The use of matching I-Section rails and a safe, simple roll-transfer principle has proved to be a satisfactory solution for carrier applications and has made possible the standardization of the engine handling system. An entire family of handling equipment has been designed to meet the requirements of engine removal, replacement, transportation, maintenance, and test. The matching rails are standard for each different piece of equipment. They are spaced 48 in. apart and incorporate quick-operating rail end couplings which permit the rails to be mated, making possible the roll-transfer of an engine from one piece of equipment to another. The engine installation and removal trailer is shown in Fig. 3. This standardized system has eliminated the need for specialized hoisting, holding, and transfer equipment.

Another factor contributing to the problem of standardization concerns special support equipment. Special support equipment is defined as "equipment which has application to one specific aeronautical model only," and is generally procured directly from the prime aircraft or engine manufacturer because of the specialized requirements. The growth of aircraft complexity and the need for many special tools and fixtures have resulted in a sixteenfold increase in the number of special tools required for one aircraft over those tools required only 10 years ago for a comparable aircraft type. The F4H aircraft with its associated support equipment indicates this growth (Fig. 4). Emphasis is continually given to replacement of this special equipment with standardized types which are applicable to many operations; however, the growth of system complexity has minimized progress in the area. Standardization efforts are constantly reviewed in the interest of economy, the best use of available space, and the avoidance of endless training of personnel. These efforts are being directed in the following specific areas:

(1) Definition of maintenance procedures and specific levels to ensure a better understanding of "where" and

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Latest addition to the ITT trainer and simulator family that includes the Nike Simulator (15D-2) and the Sonar Trainer (14E), the Universal Simulator is based on a building-block design philosophy with an open-end application potential to accommodate virtually any new electronic defense problem. This complete approach to the constantly shifting problems of electronic simulation is a prime example of the broad systems capabilities of ITT Federal Laboratories.

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"when" maintenance will be accomplished.

(2) Distribution of the technical data concerning available ground support equipment. This information, presented on "data sheets" and distributed to Navy contractors, is intended to advise the contractor of previously designed equipment which is available.

Safety

While safety is an important consideration in any equipment design program, it assumes even greater importance when the implications of an accident at sea are considered. Use of systems involving fluid pressure up to 5,000 psi, high temperatures, hazardous and flammable fluids, and the necessity for conducting frequent tests under simulated airborne conditions have created a potentially dangerous condition in the immediate area of the aircraft. Failure of support system components or even contact with fluids, such as liquid oxygen, could prove fatal if the hazard is not recognized and adequate precautions taken. To eliminate this possibility, special clothing, specifically designed enclosures, and "fail-safe" features are utilized in the support equipment. The safe movement of equipment aboard a rolling and pitching platform, such as an aircraft carrier deck, is a problem peculiar to the Navy. Positive control of equipment which weighs in excess of 10,000 lbs is of prime importance if accidents are to be avoided. Brakes which are automatically applied upon release of a tow bar and positioning trailers which are designed to remove and transport engines regardless of the ship's movement are but two of many items specifically designed for carrier use.

Facilities

In conjunction with the design criteria previously noted, it would be of interest to review the scope of certain maintenance facilities. These facilities are designed to supplement the mobile equipment provided and enable the ship to perform its assigned maintenance responsibilities. While the discussion here is limited to engines, facilities similar in scope are provided for other major aircraft systems such as avionics, hydraulics, and survival equipment.

Engine Test Facilities

Recently the first turbojet engine test stand was installed aboard the carrier U.S.S. "Coral Sea." The test stand is designed to play an important role in the maintenance mission related to the operational readiness and flight availability of turbojet-powered aircraft deployed with aircraft carriers.

This turbojet engine test stand assembly is essentially the same as those used on shore-based installations, except that the equipment is specifically designed for shipboard application. The assembly consists of three units—a control panel, an engine service stand, and an engine stand. The control panel is housed in a sound-treated booth, one side of which is formed by the aft structural bulkhead of the main deck of the carrier. The engine stand, which accommodates and restrains the engine, and the service stand, which houses auxiliary equipment required for operation of the engine under test, are installed on a special "vibration isolation" platform.

The vibration isolation platform is a novel device which is pneumatically supported by air bags similar to those used in motor coach and passenger car "air-ride" suspensions. It was provided to eliminate transmission of vibration from the carrier hull to the engine and permit the required engine performance measurements to be made accurately.

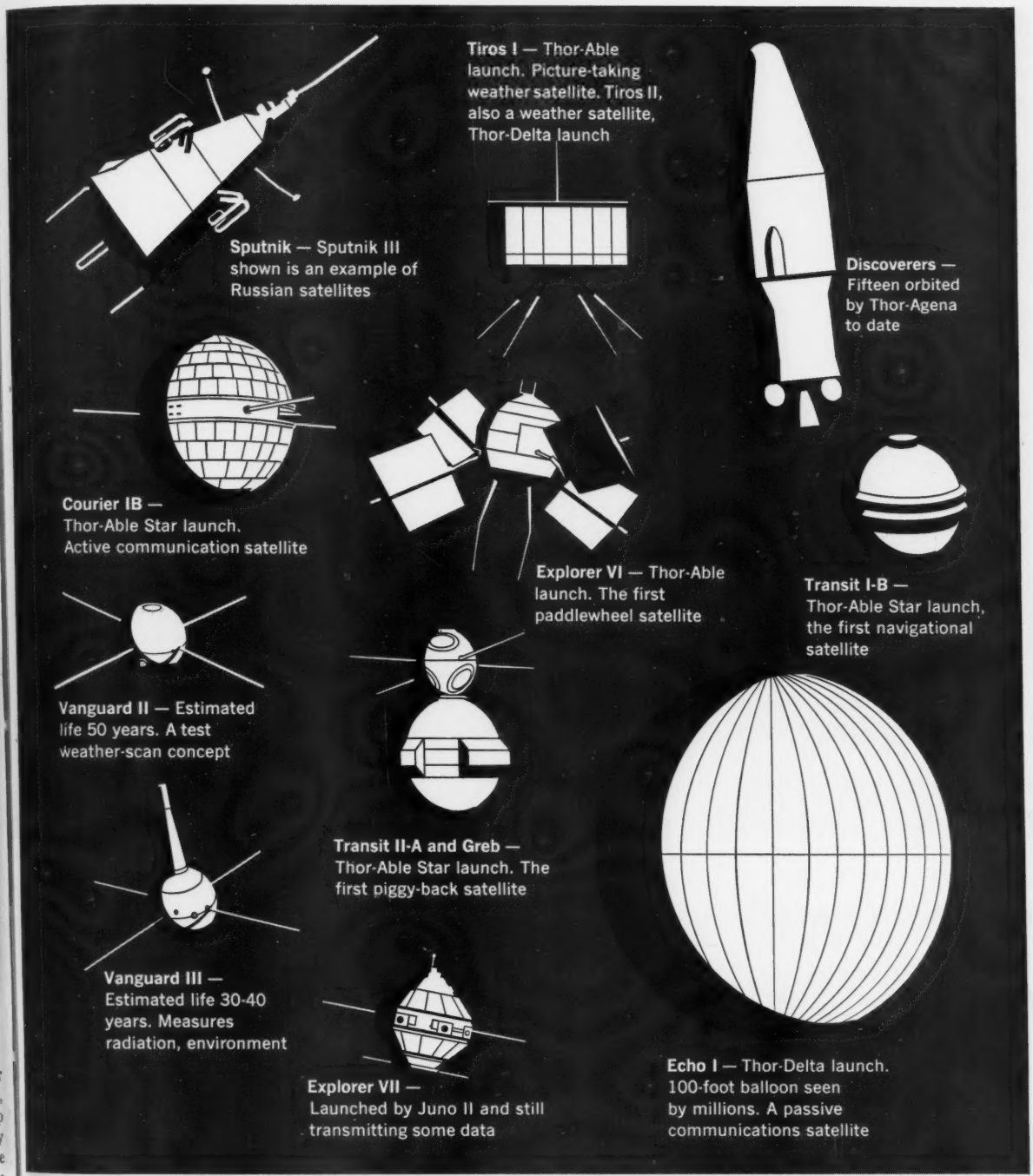
Prior to the advent of the installed turbojet engine test stand, all engines were tested in the airframe. This required respotting of the aircraft in order to make a specific aircraft available for test. It also meant that the aircraft being tested was not available for flight. Frequently, utilizing the airframe as a test bed required removal of a newly installed built-up or repaired engine because of leaks or component malfunctions which could not be corrected in the airframe.

In contrast, the installed turbojet engine test stand provides for the testing of engines which have been built-up to ensure their readiness for installation in a particular aircraft, thereby permitting the immediate replacement of engines which have been removed from aircraft for required maintenance. It also provides a capability for detecting engine malfunctions and permits testing to determine that discrepancies have been corrected prior to reinstallation of the engine in the airframe.

Engine Storage Facilities

In order to increase aircraft availability, it is necessary that storage space be provided for a reserve stock of engines, built-up in the Quick Engine Change (QEC) configuration, tested, and ready for installation when a replacement is necessary. To provide the most efficient operation possible for carriers to support this requirement, facilities are being built into the ship which will accommodate a completely built-up engine. These containers have controlled humidity and temperature and are equipped with the standard roll-transfer rails which are shock mounted to eliminate transmission of vibration from the carrier hull to the engine. With a special hoist arrangement, monorail and bridge crane combination, the dressed engine is hoisted from the engine repair area and installed on the rails in the containers. The engine is left in this container until it is needed for replacement. When required, a QEC unit is removed from the container and is immediately installed with a minimum amount of aircraft "down" time.

Fig. 5. U.S.S. "Forrestal" (CVA-59) with its complement of aircraft.


Tiros I — Thor-Able launch. Picture-taking weather satellite. Tiros II, also a weather satellite, Thor-Delta launch
Sputnik — Sputnik III shown is an example of Russian satellites
Discoverers — Fifteen orbited by Thor-Agena to date
Courier IB — Thor-Able Star launch. Active communication satellite
Explorer VI — Thor-Able launch. The first paddlewheel satellite
Transit I-B — Thor-Able Star launch, the first navigational satellite
Vanguard II — Estimated life 50 years. A test weather-scan concept
Transit II-A and Greb — Thor-Able Star launch. The first piggy-back satellite
Vanguard III — Estimated life 30-40 years. Measures radiation, environment
Explorer VII — Launched by Juno II and still transmitting some data
Echo I — Thor-Delta launch. 100-foot balloon seen by millions. A passive communications satellite

Above are some of the satellites orbiting the earth, a majority of which were launched by Douglas Thor

The Douglas Thor rocket has orbited more satellites than all other rockets combined!

Of all satellites put in orbit since 1958, 55% were launched by the Air Force-NASA Thor IRBM. In its last 83 tactical and space firings by the Air Force, Navy and NASA, 86% have been completely successful—a reliability inherited from forty years of Douglas experience in aviation and 21 years in missiles and space.

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Future Trends

The growth patterns exhibited by aircraft carrier and support equipment (Fig. 5) during the past decade give us an insight into future support equipment trends. The need for an organized evaluation of future aeronautical growth patterns and their relation to ground support equipment must be recognized if the carrier facilities—spaces and equipment—necessary to maintain future aircraft are to be provided.

It is the personal opinion of the authors that the complexity of Naval aircraft weapon systems will continue to increase during the next 10-year period. It is also our opinion that along with this added complexity, significantly improved system reliability is not likely to result if for no other reason than the increased quantity of components comprising the systems. These factors not only will create maintenance problems of increased severity, but also will complicate the logistics of support to a degree far beyond that previously encountered. Recent developments in airborne electronic systems have already spawned the development of new concepts of support which bear little resemblance to procedures employed in the 1950–1960 era.

Perhaps the most significant technical advance of the coming decade will be the broadened utilization of automatically programed line and shop check-out equipment both for faulty component identification and for subsequent modular replacement determination. This equipment will permit the use of preventive maintenance techniques, with the possibility of detecting incipient failures and system degradation. However, the time required for "hookup" and check will probably preclude flight-line use of the automatic test equipment. This function may be performed by small portable test sets utilizing Built-In Test (BIT) or In-Flight Performance Monitoring (IFPM) concepts. An anticipated increase in the utilization of automatic in-flight monitoring techniques is expected to reduce flight-line "down" time in that knowledge and location of faults will have been determined and recorded prior to completion of the aircraft mission. In-flight monitoring will not be adaptable to all aircraft, however, because of weight, space, and operation considerations.

It is anticipated that changes in maintenance methods and techniques, due in great measure to the tremendous growth in aircraft electronic systems, may cause practically a complete obsolescence of shipboard facilities during the next 10 years. Future trends will center on increased requirements for component repair to minimize requirements for spare components. Controlled atmosphere spaces may be required to enable the rework of these precision tolerance components.

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Conclusion

It is recognized that only a few of the many aspects of carrier-based support equipment have been touched upon; however, expansion of these ideas would require a treatise beyond the scope of this article. The main point of emphasis here is that support equipment is a vital factor in the operation of today's high-performance aircraft from carrier decks. It is necessary that designers of carrier support equipment recognize the limitations of the carrier environment in their basic designs to ensure that support equipment aids rather than impedes aircraft operations. It is also essential that designers of the basic aircraft recognize that the ultimate success of their efforts hinges in part on the suitability of the support equipment provided. A system which cannot be properly serviced and maintained in the field is unsuitable, particularly as a military weapon. Therefore, the requirements for support equipment should be fully considered during initial design and development phases if the optimum maintenance of the system is to be achieved.

Hawk Missile Repair Shops (Continued from page 17)

Mission Completion

Technical operators use the consoles either singly or in groups to perform the electronic tests necessary to determine the condition of each Unit Under Test (UUT).

The operators select the proper program board for the specific UUT, insert it in the programer, and lock it in place. The programer then provides the necessary routing of stimuli and power to both the UUT and the modules of the console through the preprogramed setups for testing the UUT and the adapter cables which connect the UUT to the console.

The consoles are then energized and the operators select the test sequences with the programer controls. The results of the tests are displayed visually on the indicator units of the consoles and the operators determine the condition of the UUT by observing the indicators.

After testing, the UUT is repaired and retested if necessary, and returned to the field equipment or to ordnance stock for later issue. A flow chart to illustrate this procedure is shown in Fig. 2.

Equipment Composition

Consoles

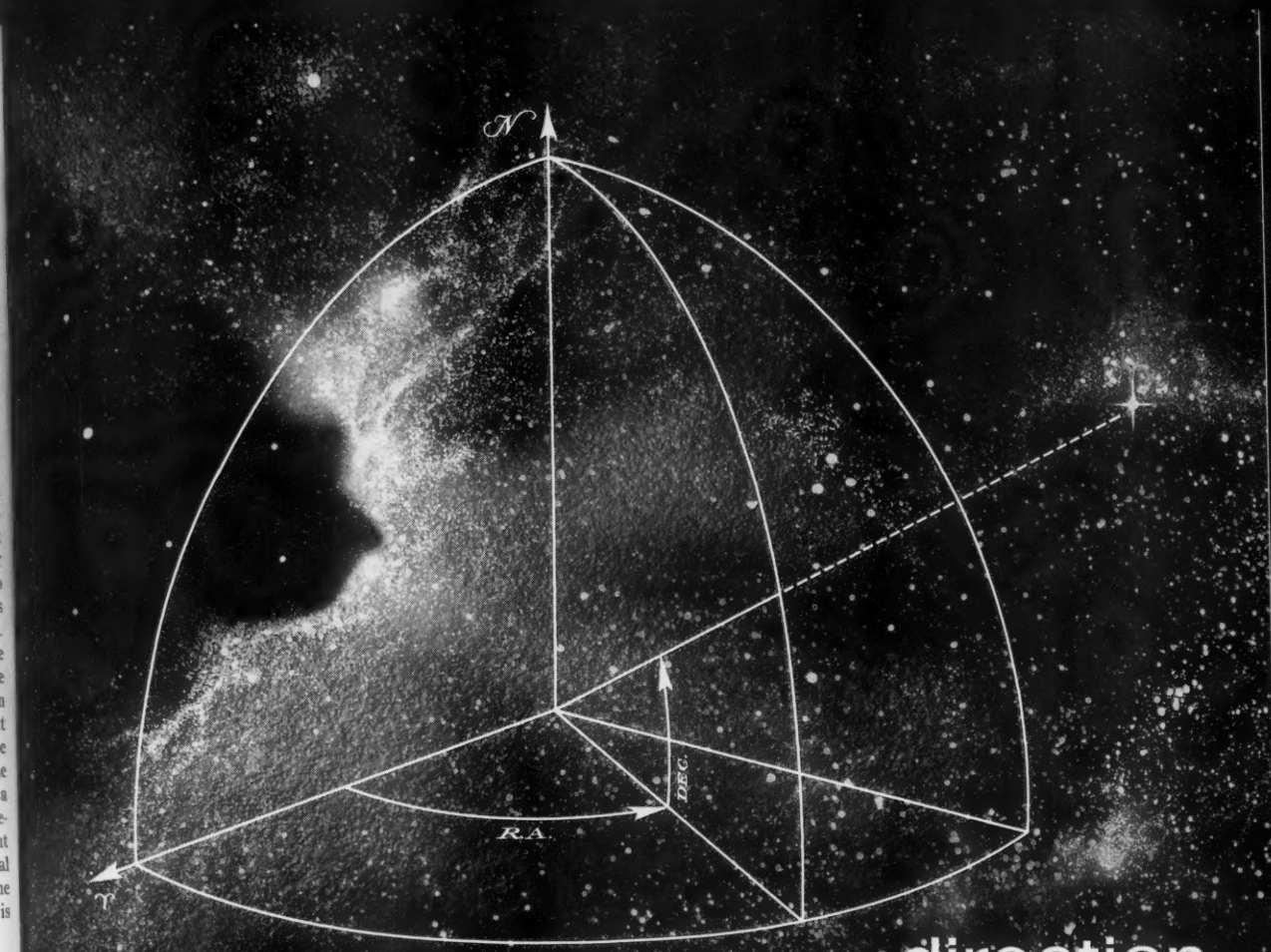
During field usage, more than one console of each type is used to physically separate certain checkout functions, and permit faster servicing of the missile system. Careful selection of test instruments, loads, power supplies, stimulus generators, programable functions, and functional combinations have kept the total number of modules and other items to a minimum, and provided extreme flexibility in application.

A typical checkout group in the field at present consists of one microwave console and four CW/Pulse consoles. The actual number used can easily be changed to meet existing demands by relocation of transportable shops as necessary.

Modules

Of the 26 different modules referred to above, 11 have multiple applications in both consoles. Eight of the eleven are used twice, one is used four times, one is used seven times, and one is used eight times. This reduces the overall cost per module and carries with it the advantages of standardization.

The use of a programing device which can be used either on a strictly semi-automatic basis or on a manually operated basis permits deviations from preprogramed setups for the units under test, in order to more easily find existing troubles. A programed setup might show that a certain voltage is incorrect during a given test. Without changing the general test pattern, it is possible to utilize one or more of the test instruments to help pinpoint the trouble.



direction

Once off the firm footing of earth, the most critical need of any vehicle is for precise *direction*. The straight course of a sub, a ship, a jet... the precision track of missile or space vehicle... these result from a directional reference of superior accuracy; the kind provided by gyros made at Sperry. Whatever the application, gyros by Sperry have a common denominator: stability. Sperry is dedicated to, concentrates upon, stability – absolute directional accuracy, absolute repeatability. The result is seen in the widespread technological successes achieved at the direction of the Sperry gyroscope. General offices: Great Neck, N.Y.

Sperry gyros are the precise directional reference in these and many other applications: pinpoint navigation for the Polaris subs; automatic steering for advanced vessels such as the N.S. Savannah; automatic flight controls for the DC-8 and other aircraft; precision bomb-nav system for the B-58 "Hustler"; miniaturized gyros for space vehicles (symbolized in main illustration).

SPERRY

Programing of functions and ranges of all controlled modules is accomplished automatically for each particular test setup (provided the programer has been set to "automatic"). The switching itself is done by solenoid operated, rotary switches contained in the controlled modules, but the programing is accomplished by the predetermined setups required for the specific tests being performed.

Indicators

Direct reading, multiple-range, semiautomatically programed analog type indicators are used for several reasons, but the principal one is that the requirements of the system are nearly all analog in nature. Other reasons include:

(1) Versatility of equipment without extensive program changes.

(2) Simplicity of operation of analog devices.

(3) Minimization of the number of instruments required for system testing.

(4) Minimization of errors due to conversion of units and scales with indirect reading instruments.

(5) Minimization of training program time for technical field personnel.

In addition, use of digital indicator devices would require complex digital-to-analog and analog-to-digital conversions. Since nothing could be gained except additional complexity, if digital equipment were used, analog indicators were chosen. The sole exception to this rule was the counter which had to accommodate a wide range of frequency counting functions. To satisfy this requirement, digital means were found to be more useful for this task.

Stimulus Generators

There are three general types of stimulus generators in the consoles; (1) unmodulated CW, (2) modulated CW, and (3) pulse. In general, all stimulus generators are multiple-range units whose precise outputs at any given time are determined by the automatic programing for a particular test. The operator can intervene and alter this program with manual controls.

The unmodulated CW generators cover wide bands of frequencies, ranging from 1 cps to 500 kcps, and a large portion of the radar intermediate frequency band. Included in these ranges are several single-frequency outputs for special purposes. Almost all stimulus generators are provided with amplitude controls for variation of their output voltages.

The modulated CW generators provide for amplitude and frequency modulated signals, either separately or together. Noise modulation is also provided when required by the specific test program. In addition, modulating signals are provided by the console for the external "X" band microwave generator used with the system during tests.

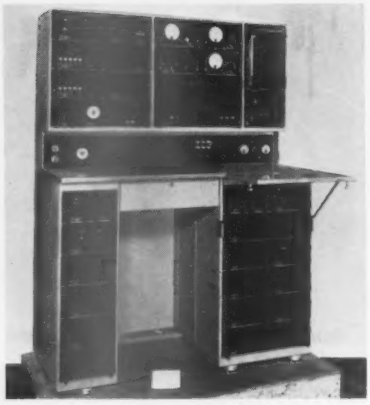


Fig. 3. Console.

The pulse generators provide outputs which are variable in repetition rate (40–1000 pps), pulse width (1–2500 μsec), and amplitude (0–100V). In addition, provision has been made to slave one to the other and provide pulse delays.

Due to the large number of system requirements for different power values (both a.c. and d.c.), programing of these supplies became necessary. In addition, this reduced the number of power supplies in the consoles, and reduced weight and space.

Expandability

The original equipment provided for economic expansion of the testing capabilities. The soundness of this feature has been proved by later modifications to increase the testing capabilities of the consoles. New units have been added as needed without difficulty and at a minimum of cost.

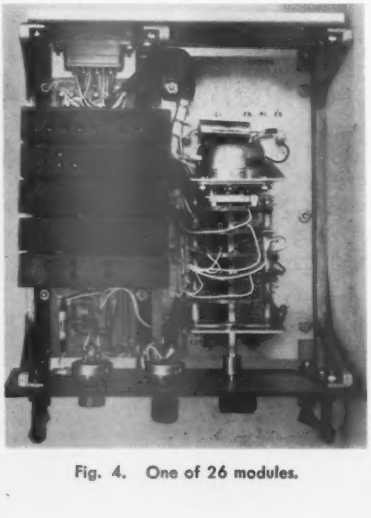


Fig. 4. One of 26 modules.

Self-Check

Self-checking capabilities have been incorporated into all consoles, to check out their own circuitry using appropriate self-check programs. In this manner, the calibration of console units may be checked at any time, making the shop equipment fully self-sufficient.

Transformer and Relay Assemblies

The transformer and relay assemblies are mounted in the pedestals of the consoles for centralized a.c. power distribution and control. Time delay relays are used to provide simultaneous protection to all of the modules by delaying application of all high voltages until the module filaments have had time to warm up. Thus, vacuum tube life expectancy has been increased and failure rate reduced.

Standardization

Equipment

The standardization program for the Hawk missile field maintenance equipment is based on studies made for the Army Ordnance Corps and other services by RCA and others. The concensus of these studies clearly indicates that numerous advantages can be gained from such a program. Some of these are:

(1) Cost reduction.

(2) Better specification and control of component parts.

(3) Greater reliability.

(4) Production economy (other than costs).

(5) Multiple rather than single usage items.

(6) Unit interchangeability.

(7) Simplification of field maintenance problems.

(8) Simplification of logistic problems.

Design Concept

The design of the Hawk field maintenance equipment was directed along a path of standardization. A suitable compromise was made in which standardization was carried as far as practical without limiting the capabilities of the end product in its mission to fulfill all system test requirements. Present development of standardized equipment such as the RCA DEE family (Digital Evaluation Equipment) permits even further reduction in the number of specialized units.

Drawer Design

The Hawk system test equipment was designed around a standardized drawer size; only multiples of the basic drawer size were used (Fig. 1).

Front panel sizes with widths of one, two, three, and four times the basic width, and one or two times the basic

Said Isaac Newton:

"Every particle of matter attracts every other particle with a force directly proportional to the product of their masses and inversely proportional to the square of the distances between them."

Until recently, the thrust which propelled rocket vehicles into their coast stage, prior to orbiting, was provided by booster stages. The fuel carried by the satellite stage was used only to inject itself into orbit.

Now, however, a scientist at Lockheed Missiles and Space Division has evolved a Dual Burning Propulsion System which allows higher orbits and heavier payloads. With this system, the satellite vehicle fires immediately after the last booster stage burns out, thus augmenting the begin-coast speed. Later the satellite stage is re-started to provide orbit injection.

An even more recent development by Lockheed is a triple-burning satellite stage. This will permit a precise 24-hour equatorial orbit, even though the vehicle is launched a considerable distance from the equator.

These principles have made possible the early development of the MIDAS satellite. Moreover, they substantially increase the altitude and payload of the DISCOVERER series. Lockheed, Systems Manager for these programs and for the POLARIS FBM, is pursuing even more advanced research and development projects. As a result, there are ever-widening opportunities for creative engineers and scientists in their chosen fields.

Why not investigate future possibilities at Lockheed? Write Research and Development Staff, Dept. M-15B, 962 West El Camino Real, Sunnyvale, Calif. U.S. citizenship or existing Department of Defense industrial security clearance required.

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height were used. Only one module in each console required a double height panel. Present module front panels vary only in width, 20 percent are single width and 75 percent are double width.

To further standardize the drawer size, the depth of all drawers was held constant. This simplified construction through the use of standardized racks. An additional advantage of this feature allows new arrangements of modules to be created with only minor modifications of rack wiring and/or module opening size in the rack.

Module Design

At the module level, standardization of hardware has been carried beyond the "screws and nuts" stage, and has been extended to include common basic parts such as module sides frames, rear panels, printed circuit support frames, module connectors, and printed circuit connectors. The basic panels and frames are modified as required for particular applications.

Mass production techniques may be utilized for production of these basic items. Only two types of connectors are used for module connections, and only one type for the printed circuit cards.

Component Standardization

Standardization of components and materials within the modules is carried as far as is possible within the design requirements of the individual modules. Every attempt has been made to restrict components and materials to military standards. Reliability is enhanced, and procurement and quality control problems are minimized.

Console Design

The console racks also use standardized hardware, components, and materials. In addition, welded construction is used for all basic rack framing, and jig assembly techniques are used for positioning all detachable frames and module guide rails. In this way, uniformity of the product is assured, and interchangeability of identical modules between consoles is completely realized.

Mechanical Design Features

Modules

All modules are removed from the front of the console. Module support, positioning, and alignment are accomplished by guide rails which mate with guide slots in the rigid side frames of the modules. This arrangement eases insertion and removal of the modules, and precludes connector misalignment problems.

Module retention in the console is accomplished by use of locking cam type handles on the front panels of the modules. The same handles provide cam action removal of the modules for servicing.

Module location in the console has been determined on a human engineering and functional basis. All indicating devices are located above the work table of the console; the power supplies are located in the pedestals below the work table; and modules with frequently used controls are located in the center and toward the right side of the upper console.

Programer

The programing device is located at the right side of the upper console, so that all of its operational controls are located within easy reach of the operator. The entire programer assembly may be removed as a unit for service. It is panel-mounted, and all connections are made with pluggable connectors.

Front Panels

Five front panels in the recessed intermediate section of the console contain all the circuit breakers and fuses for the various a.c and d.c. power supplies. In addition, convenience outlets, and elapsed time meter, and most of the connector receptacles for test cables are provided on these panels. The recessed position of the panels provides a large work surface and also protection from accidental damage to the panels.

Wiring

The internal wiring of the consoles is composed almost completely of replaceable wiring harnesses. (The only exceptions to this general case occur where jumper wires are required within subassemblies.) This feature permits individual assembly of the harnesses and the racks, thereby reducing production time for the console. In addition, labor costs for this type of assembly are much lower than they would be for point-to-point wiring. Whenever possible, the wiring harness concept was extended to the modules.

Cooling

Forced-air cooling is supplied to all parts of a console by a single simplex blower which is energized at all times during operation of the console. The ambient temperature of the entire console is kept within safe limits at all times and the failure rate of components and modules is reduced to a minimum.

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Range Safety—a Necessary Evil (Continued from page 21)

the impact probability density distribution will be a more complicated curve —nonmonotonous, with maximums at distances from the launcher approximately equal to the ranges of the standard impact points of the stages.

For vehicles launched to put a payload into orbit around the earth (orbital mission) or onto a space trajectory (escape mission), malfunctions can cause impact at any point on the surface of the earth. Again the impact probability density, because of possible malfunctions, will not be uniformly distributed over this potential impact area, and similar considerations as above apply (Fig. 3). The following is a description of a possible model for the entire impact probability density distribution pertaining to an orbital mission.

It is assumed that a three-stage vehicle will be used. At two distinct points along the IIP line, an accumulation of impact probabilities describes the impact of the first and second stages of a properly performing vehicle. The third stage is supposed to go into orbit. A ridge extends along the IIP line and its continuation (which may be considered the projection of the orbit onto the surface of the earth). This ridge accommodates the impact probabilities resulting from both premature propulsion termination and/or pitch program errors and makes allowance for lateral dispersion not caused by a bias-type malfunction of lateral control.* The width of the ridge will not vary too much, but its height should decrease with distance from the launcher. In defining the height of the ridge, an allowance also has to be made for the probability, small as it might be, of tilting backward.

* The width of this ridge is determined by atmospheric disturbances influencing the re-entering parts and by the deviation due to gross malfunction of control, causing the vehicle to tumble. A small bias-type malfunction, however, can cause the vehicle literally to go off on a tangent.

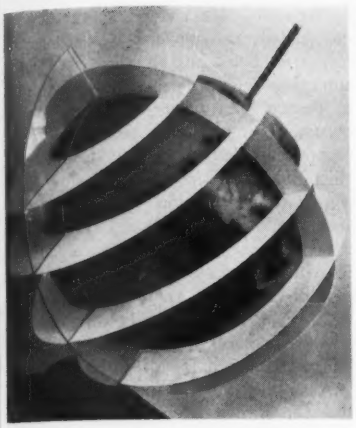

Fig. 3. Simplified model for the impact probability density distribution of a malfunctioning vehicle for a space mission (earth orbit or escape trajectory). Here it is assumed that the impact probability density is greatest along the IIP line, decreasing linearly with distance from the launcher and decreasing according to a cosine law with angular distance from the IIP line. The impact points of the stages of the vehicle (and the "legitimate" scatter around them) are not shown.

The rest of the globe is covered by a "blanket" of impact probabilities whose thickness decreases in some fashion with the angular distance from the IIP line. This "blanket" describes the impact probability distribution for vehicles subject to malfunctions causing lateral deviation, possibly combined with premature propulsion termination.

To the knowledge of the author, no consideration has been given thus far to possible range safety problems resulting from a vehicle returning from space. For many satellite missions, such return will not be necessary, and consequently the construction of the spacecraft is likely to permit burn-up during re-entry. But for some missions where recovery of the spacecraft or part thereof is required (manned spacecraft or data capsule), the resulting range safety problem must not be disregarded. Of course, the mission should be designed in such a way that no range safety problem will result from spacecraft recovery as planned. However, a spacecraft, constructed so that it will withstand the strains of re-entry, will pose a range safety problem in case of malfunction of the return and/or re-entry maneuver.

Possible Influence of Range Safety Activities

It can be assumed that a prudently planned trajectory for a multistage vehicle, for instance, is laid out in such a way that the impact points for the stages fall into the ocean, sufficiently removed from inhabited land masses. Consequently, no particular range safety problem would exist if all vehicles were performing as planned. This would be true even if the IIP line crossed over inhabited land masses. However, malfunctions, like premature termination of propulsion, could in such "overflight" cases result in impacts on land. If the IIP line does not cross over but passes close to inhabited areas, a hazard exists from malfunctions causing azimuthal deviations, possibly in combination with premature thrust termination. Therefore, in general, if the mission permits, trajectories are selected in such a way that overflight is avoided and an ample margin between the IIP line and the nearest land mass is provided.

While a more detailed technical description of range safety activities will be given in the following section, some general considerations appear appropriate at this point. The discussions thus far appear to indicate that, by appropriate planning, any hazard to inhabited land masses can be avoided. This thought, however, merits closer consideration. It was mentioned before that the potential impact area for any vehicle is quite extensive and may for some cases encompass the entire earth. Only by appropriate range safety activities, therefore, can protection be provided. Such is being done by restricting the possible impact points of a vehicle to a certain area which may be pictured as a band extending on both sides of the IIP line. If the potential impact point shows a definite tendency to leave this band, flight termination action will be taken. Under ideal conditions, absolute protection could be provided for areas outside a given band extending on both sides of the standard IIP line. The dimensions of the band to which the impact points are supposed to be restricted, and of the band outside of which absolute protection could be

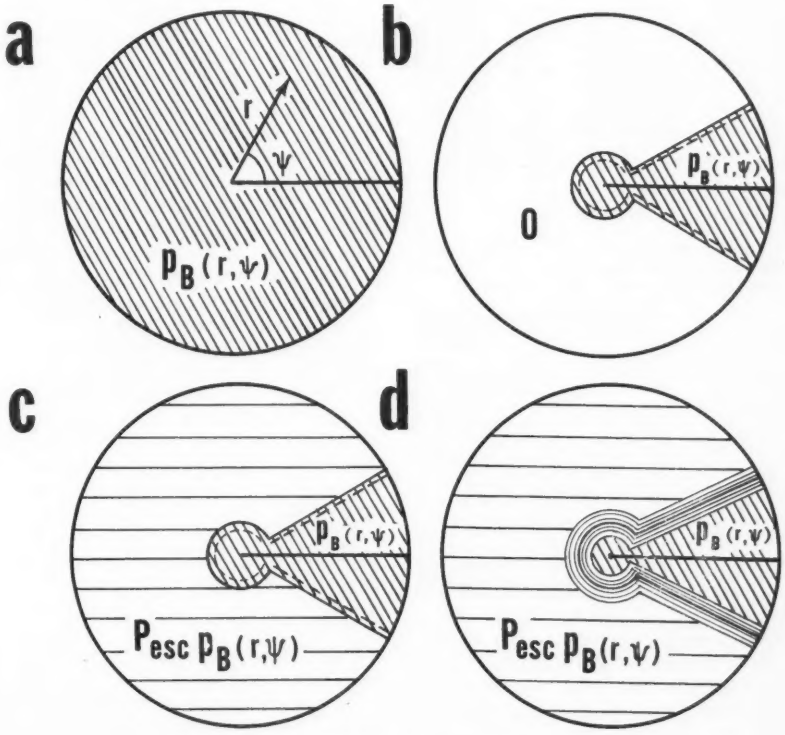

Fig. 4. Schematic description of range safety activities, a ballistic missile:

(a) No range safety action; impact is possible at any point within a (roughly) circular area around the launcher; the impact probability density p_B, however, will vary with distance r from the launcher and azimuth deviation Ψ from the intended flight line.

(b) If range safety action were absolutely reliable and instantaneously effective, the impact probability outside a given sector could be reduced to zero; inside, it would remain unchanged. However, there would be an accumulation of impact probabilities right along the boundary lines owing to the range safety action taken on vehicles which otherwise would have achieved impact outside.

(c) Since range safety action cannot be absolutely reliable, there is a chance, P_{esc}, that flight termination command remains without result; a vehicle may thus escape the range safety action. Consequently, the impact probability density in the area to be protected—i.e., the area outside the given sector—will be $P_{esc}\,p_B(r,\Psi)$.

(d) Because of inherent delays, combined with velocity vector turning capabilities, etc., the impact probabilities for those vehicles for which flight termination action is taken and is effective will accumulate within a band extending on both sides of the originally defined boundary. Consequently, maximum protection (though not absolute protection) is provided to areas outside the outer edge of the band extending along the original boundary.

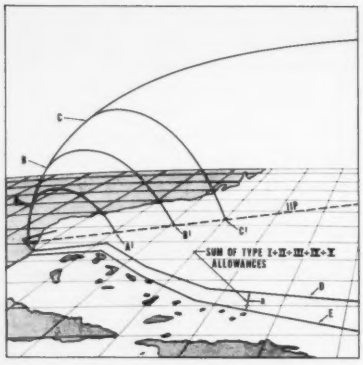

Fig. 5. Arbitrary trajectory, pertinent instantaneous impact line (IIP), envelope *E*, to land masses to be protected (only right-hand area shown), and destruct line *D*. If flight is terminated at points *A*, *B*, or *C*, impact will occur at points *A'*, *B'*, or *C'*, respectively. The offset *a*, of the destruct line *D*, from the envelope *E* is indicated for one point.

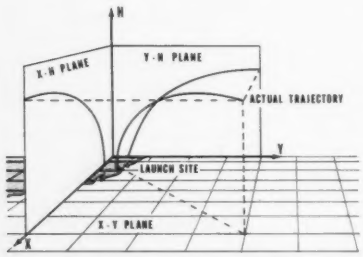

Fig. 6. Projection of an (arbitrary) trajectory into three planes used with real-time position indicating range safety equipment.

guaranteed under these conditions, are of course, slightly different due to an allowance which has to be made for instrumentation inaccuracy. Besides the possibility that the available range safety intelligence might be biased because of some instrumentation error, failure to execute the command for flight termination, obviously, could cause impact outside the band mentioned before. Consequently, absolute protection cannot be provided anywhere. Selecting a trajectory in such a way that the IIP line and the "exposure band" do not cross land masses can minimize the hazards (Fig. 4). However, such specific trajectory selection is not always possible.

Protection by Present Range Safety Philosophy

Information about the in-flight behavior of a vehicle must be provided to the range safety officer in a form suitable to enable him to carry out his task. This information consists of, or is based on, optical observations (vertical wire sky screen, television sky screen, and optical sky screen, which give qualitative results; and optical tracking systems yielding quantitative data) and electronic tracking (radar, beat-beat or ELSSE systems, AZUSA, telemetry, and impact predictor, all yielding quantitative data). Because of the inherent limitations of these sources of information, generally the propelled flight phase(s) will be subdivided into various subphases. Such instrumentation then is selected as a primary source of information for a respective flight phase which has the greatest sensitivity under conditions prevailing in that phase. In order to safeguard against instrumentation failures (gross misindication or complete dropout), each phase has to be covered by more than one instrument. Such redundancy may be supplied by instrumentation systems of the same type, as long as they are independent of one another; if different systems are used, they should provide data of the same degree of quality. This latter condition, however, is not always met by range safety instrumentation presently in use.

The information thus provided about the in-flight behavior of the vehicle is compared with the predicted nominal behavior and limiting conditions in a reference frame commensurate with the source of the information. The construction of these limit lines can be most easily explained for the case of an impact predictor. For all other instrumentation providing quantitative information, the construction of the appropriate limit lines follows, at least implicitly, from that for the impact predictor.

An ideal "real-time impact predictor" —in the true sense of the name—would indicate at any instant during propelled flight where the vehicle would impact if propulsion were terminated at that instant. Obviously, the trace plotted by an impact predictor will coincide with the nominal locus of impact points only if in actual flight the vehicle follows exactly the precalculated trajectory. Deviations (for instance, due to wind influence) during propelled flight will result in deviations of the actual line plotted by the impact predictor from the preplotted nominal IIP line. For future reference, deviations of this type will be designated *Type I deviations*.

Since no technical device is perfect, all kinds of instrumental inaccuracies come into play—for instance, tracking inaccuracies, inaccuracies resulting from digital-to-analog conversion, rounding-off inaccuracies in the calculation of the coordinates of the predicted impact point, simplification in the computer program used for impact prediction calculation, and plotting inaccuracies. All these possible inaccuracies combined will be referred to as *Type II*.

There is another type of possible deviation which needs some detailed consideration. The impact predictor is a high-speed computer teamed with appropriate input sources (for instance, radar or AZUSA). Real-time position information is fed into the computer which smoothes and differentiates these data to derive "real-time" velocity components. Using position and velocity, the computer calculates the coordinates of the point where the vehicle would impact were its propulsion terminated instantaneously. The coordinates of this point are continuously displayed on a plotting board. From this description it is obvious that there cannot be any "real-time impact prediction" in the true sense of the word. Smoothing and differentiating of position data already provide the velocity for a past instant; also, the impact calculation proper takes time. The intelligence displayed by the impact predictor can, therefore, be said to be lagging behind reality. Consequently, an allowance is made for the maximum deviation which could possibly develop during this lag interval. Assuming that the velocity vector turns laterally as fast as physically possible for the given interval, the additional lateral velocity thus accumulated is multiplied by the so-called "time remaining" to calculate possible lateral deviations. "Time remaining" is the time interval from the instant under consideration to impact if propulsion were terminated at that instant. These deviations will be referred to as *Type III*. It is practical to include in the Type III deviations an additional allowance for the reaction time of the range safety officer.

If the range safety officer does terminate propulsion at any given time, such action is conventionally coupled with destruction of the vehicle. In case of a liquid propellent vehicle, this is done for two reasons. If it were desired to terminate propulsion by giving cutoff command only, actual thrust would continue for a finite time interval for technical reasons (valve closing time, etc.). Destruct of the vehicle, of course, is the fastest means of terminating propulsion. Another reason for destructing the vehicle is the desire for "fuel dispersion"—i.e., preventing the explosion of large amounts of fuels at impact. The debris resulting from destruct action will impact in a scatter pattern around the hypothetical impact point of their common center of mass. Consequently, an allowance for this scatter and possible wind influences upon the re-entering pieces will have to be made. This allowance may be designated *Type IV*.

An additional allowance is made in general for the fact that the geographical location of the areas to be protected is known only with limited accuracy. This allowance will be named *Type V*.

In order to provide maximum protection to given land masses, therefore, the actual IIP is not permitted to cross over a line which is commonly called the "destruct line." This destruct line is

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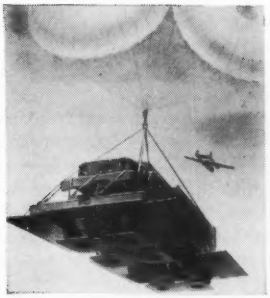

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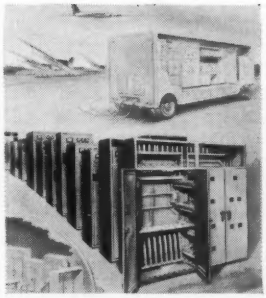

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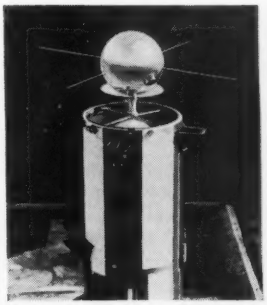

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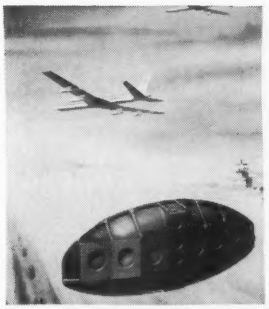

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defined as a line offset from an envelope to the land masses to be protected by amounts combining the allowances Types I through V mentioned above. Because the flight conditions of a vehicle change with flight time (for instance, the velocity vector turn angles which can be accumulated during a given time interval), the destruct line is not parallel to the envelope of the land masses. It is obvious that maximum protection is achieved by adding all these allowances arithmetically (Fig. 5).

If the nature of the experiment does not impose any launch azimuth restrictions, the mission planner should select a launch azimuth which leaves an adequate margin between the nominal IIP line and the destruct line. If, on the other hand, the experiment requires a certain launch azimuth, and the resulting IIP line violates the conventional destruct line, either the experiment cannot be carried out or certain requirements of the conventional range safety policy must be waived. Ordinarily, in such cases the conventional range safety requirements have to be met wherever possible and the quality of the actual trajectory has to be assured at the time just before a given waiver applies. This restriction can be visualized as the condition that the vehicle can enter a danger zone only through a narrow window, selected in such a way that it can be reached only by a vehicle that has performed satisfactorily up to that point.

The unique factor of the impact predictor—namely, the ability to calculate the future impact point on the basis of present position and velocity information—is not inherent in other range safety instruments. They may be classified as real-time position and velocity indicators. The real-time position derived from a tracking radar, for instance, is displayed on a plotting board and the direction of the pertinent velocity can be recognized from the slope of the developing position curve. The chart on the plotting board shows preplotted an appropriate projection of the nominal trajectory (Fig. 6) and one or two families of range safety curves. These range safety curves are determined in the following way.

It is assumed that at any time after take-off the distance from the launcher, and the speed reached, are the same as in the nominal case. With these assumptions, the direction of a specific velocity vector (in the appropriate projection) is constructed for each point on the plotting board. The absolute value of this specific velocity vector is equal to that of the nominal velocity vector pertaining to a position on the nominal trajectory having the same distance from the launcher as the point under consideration. Its direction is selected in such a way that impact would occur on a so-called impact limit line should propulsion be terminated at the instant the missile position coincides with the point under consideration. The impact limit line is equivalent to the destruct line derived in the preceding discussion of the impact predictor. Of course, it is not identical with it. A different allowance for the Type III deviation has to be made since the characteristic time lag for the real-time position plotting board is, in general, different from that for the impact predictor. Furthermore, an additional allowance has to be made for the obvious shortcoming of the assumption that distance gained and speed achieved at a given point are independent from the actual flight path through which this point was reached. Of course, these charts are valuable only as long as no gross deviation has taken place. Another allowance is made for the inaccuracy in guessing parallelity of two curves. These velocity directions constructed for all points on the chart define a family of curves, the range safety curves for the respective projection (Fig. 7). If one such projection can take care of two different impact limit lines (for instance, to prevent large deviations to the left and to the right of the nominal flight path), two such families of range safety curves will be shown. Flight is terminated whenever the trace of the actual flight parallels one of the neighboring range safety curves.

In general, projection is made into three planes—the ground plane and two vertical planes.

Space Age Demands on Range Safety

The presently used range safety philosophy may be considered adequate for the development of ballistic missiles, though in a number of cases it proved to be quite a hindrance, and in general it complicated the flight-test program. For instance, the requirement to provide maximum protection to land masses necessitated selection of targets well clear of land masses, and thus deprived the missile developer of benefits he could otherwise have derived from land-based instruments observing the terminal flight phase. The early space program, content with putting a satellite into any orbit, did not yet feel the fetters of this philosophy. As the space program grew more sophisticated, however, its demands clashed with those of the current range safety philosophy. Thus an orbit with a prescribed inclination—necessary for the exploration of the lower edges of the Van Allen belt, for instance—can be achieved from a given launch site either by *dog-legging* (changing the flight azimuth during flight), if the launch azimuth is restricted, or by a launch azimuth resulting in an IIP line crossing over or passing close to certain land masses. In general, technical restrictions imposed by the available booster power ruled out the former approach; therefore certain requirements of the range safety philosophy had to be waived for such launchings. In some cases compromises were made between the requirements of the experiment and these range safety restrictions.

Future space exploration will, as a rule, demand waivers of the range safety requirements if the present philosophy is upheld, while the number of easily accommodated cases will decrease. Obviously any regulation which has to be

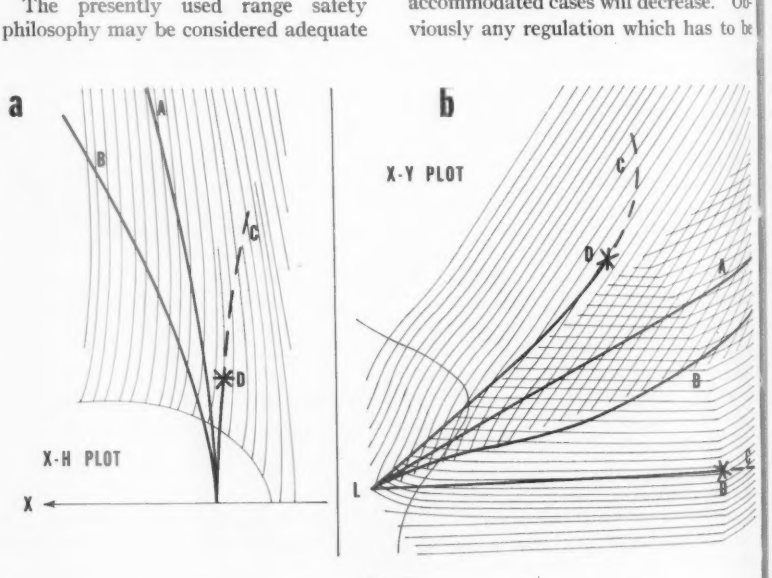

Fig. 7.

a = actual X-H plot, of an arbitrary trajectory
b = actual X-Y plot, of an arbitrary trajectory
A = projection of nominal trajectory
B = permissible trajectory
C = nonpermissible trajectory; as soon as the projection of the trajectory parallels neighboring range safety lines (at D), flight termination action is taken.

suspended more often than it can be upheld has outlived its usefulness.

The demand for a modification to result in a less restrictive range safety philosophy is actually not radical. The reluctance to carry out this change can be explained psychologically by the aversion of the populace to any new and unusual technical device. Unfortunately, ballistic missiles and the technically related space vehicles are still included in this category, while airplanes seemingly have outgrown this stage. After airplanes had demonstrated an acceptable performance over the years, at least statistically, their flight over congested areas is now regarded as commonplace, although their probability of malfunction is indeed greater than zero. Airplanes do occasionally fall into heavily populated areas.

It is encouraging to note that the need for less restrictive range safety rules has been recognized elsewhere; see, for example, reference 1. But it appears that the fruits of such endeavors were never harvested.

Opponents of the demands for modernization might argue that the presently used philosophy is capable of accommodating complicated space flight experiments via appropriate waivers, and discount the relative frequency with which these waivers are needed. However, waivers are granted—if at all—only after a detailed analysis of the proposed launch trajectory, of the resulting hazards if the waiver were granted, and of the effects on the experiment in case the waiver were not granted. The data on which such analysis is to be based become available only shortly before the planned launch date (a commitment on the final weight data needed for the trajectory calculation, for example, is habitually hard to acquire). Consequently, most of the planning and development phases have to be entered into and carried through without any assurance that the experiment will finally be permitted.

What then should this modernized range safety philosophy look like? It should be of such a nature that reasonable planning for space experiments is possible within well-defined limits so that the permissibility of the experiment does not remain uncertain until shortly before the planned launch date. More specifically, the new philosophy must permit overflight—that is, the IIP line must be permitted to cross over land masses. But it would be unreasonable to demand that stage impact points may fall on land; the philosophy must spell out an appropriate requirement. It would be imprudent to endanger land masses by an obviously erratic vehicle; therefore the range safety rules should contain appropriate restrictions. The requirement that the IIP line, as it develops in actual flight (or the actual trajectory), pass through a given window just before the actual IIP enters onto a land mass would be a criterion by which to determine continuation of the flight. With these restrictions, the impact probability density on land should turn out to be tolerable, though obviously not zero.

If overflight is permitted—and it has to be—restrictions in the lateral direction also need not be extreme. In the construction of the limit lines, therefore, the various contributing factors should be combined statistically rather than arithmetically. Furthermore, the contribution stemming from the velocity vector turning capability should be treated as a statistical entity in itself, instead of using the maximum turn angle the vehicle is physically capable of achieving. In this way, destruct lines could be drawn closer to land masses, permitting nonzero, though small, impact probabilities on land. The permissible impact probability density should be derived by a consideration of the resulting hazard—i.e., a combination of impact probability density, population density, and so-called "lethal area," a characteristic for each given vehicle. Lethal area is defined as that area around the theoretical impact point within which damage or injury to property or persons could result. The defining parameters for the destruct lines then should be adjusted in such a way that the hazards resulting from possible impact compare favorably with everyday hazards (industrial, traffic, etc.).

The planning of a given experiment, therefore, is seen to be a complicated endeavor. It should not be done in a ruthless manner, disregarding all range safety considerations. It should be free of hypocrisy and/or favoritism—the difference in the degree of protection afforded different geographical areas should not be governed by any nontechnical considerations. The maximum protection compatible with the requirements of the experiment should be provided. If dog-legging is possible without being detrimental to the experiment, it should be applied. But dog-legging applied in one phase of the trajectory might reduce the hazards in one area and increase them in others. Consequently, the trajectory planning turns out to be an optimization process. An honest optimum is obviously reached when all the means of trajectory shaping, compatible with the requirements of the experiment, have been used in such a way that the sum total of the hazards is minimized under the additional restriction that in no place the hazard exceed a predetermined maximum.

From the foregoing it is clear that such optimization necessitates a number of trial-and-error trajectory calculations combined with other variational calculations—a time-consuming process. This fact underlines again the need for clearly defined guidelines. Nobody can be expected to invest the effort, time, and expense necessary for such an optimization study if he has no guidelines and must, after all, still fear that his endeavors may have been in vain, or that he could have gotten by with much less work.

The modernized range safety philosophy must also provide for problems stemming from re-entering space vehicles. Here it might be wise to distinguish between manned and unmanned re-entry vehicles. The group of manned vehicles, of course, will have to be subdivided into two classes—those of a ballistic type and those of an airplane type. The former, in general, will not be capable of corrective maneuvering during the latter portion of re-entry, while the airplane type of vehicle will have this capability. If the airplane type does not carry restartable engines (glider type), its maneuvering capability, of course, is limited. For the ballistic type of re-entry vehicle the impact point will have to be planned in an area where no hazard exists and where considerable dispersion is permissible. For the maneuvering type, it can be expected that landing will be planned at an air base. The hazards stemming from a vehicle capable of maneuvering under power should not be different from those of any conventional aircraft. Because of the postulate that the modernized range safety philosophy must permit nonzero impact probabilities anyway, the hazards of the landing spacecraft will not pose any unusual problem. For the calculation of the hazards resulting from re-entry out of orbit, conditions apply which are somewhat different from those describing the hazards which exist because of possible malfunction during ascent into orbit. While in the latter case, impact is possible at any point on the earth's surface, the impact possibilities of the former will be restricted to a band of latitudes essentially determined by the inclination of the orbit. (Of course, in case of a polar orbit, impact again is possible at any place.)

Instrumentation Requirements

On the one hand, no responsible range safety officer would be content with a single command channel for taking range safety action; on the other, he is content with dual channels (regarding practical limitations). It is reasonable, therefore, to demand that he should not base his decision to take flight termination action on the indication of only one instrument. This demand is specifically justified by previous unfortunate experience resulting from action taken by a range safety officer on the basis of the indication of one instrument which—after the fact—was proved

to have displayed biased information. Practical limitations, of course, prohibit the demand for simultaneous coverage by a great many instruments. However, the minimum requirement should be that flight termination action be taken only if at least two out of at least three instruments providing data of the same degree of quality (and preferably of the same degree of reliability, too) so require. Should coverage by some of those instruments have been lost—e.g., in case that information is available from only two instruments, and the indications of these two instruments contradict one another—it should be the option of the range safety officer to decide whether he wants to consider the combined information as unknown or whether he should put his trust in one of the two instruments. This decision will have to depend on the overall experience of the range safety officer with the respective instruments as far as their reliability is concerned.

Present methods of application of range safety instrumentation can be improved. The largest contribution to the distance by which destruct lines have to be offset from land masses to be protected generally is given by the Type III deviations (velocity vector turning angles). By reducing the time interval Δt by which the displayed intelligence lags behind reality, these Type III deviations can be reduced appreciably. Thus, for example, by combining direct position measurements (from a radar) with quasi-direct velocity measurements (from a Doppler system modified to remove ambiguities), one can save that portion of Δt which, in the currently used impact predictor system, is required to edit, smooth, and differentiate position data. Such a system (RADOP) has been recently proposed and can presumably be made available with a minimum lead time. (See also reference 2.) A few words are necessary concerning quasi-direct velocity measurement, as well as technical improvement of the impact predictor. Velocity determination from Doppler-type information amounts to taking the difference of cycle counts at fixed time intervals. Thus it is evident that this type of velocity information also is already superseded when it becomes available. But, since simple differencing appears sufficient, it follows that the degree of obsolescence of this type of velocity data should be less than that of velocity data derived by a more complicated calculation process—e.g., from smoothed position data by numerical differentiation. Of course, some benefit can also be derived from the use of a faster computer. There is a movement afoot to replace in one specific case the presently used IBM-709 computer with a more versatile and faster IBM-7090. The additional capacity and speed of this computer are planned to be utilized in a rather fancy way—to accept simultaneously inputs from several sources, smooth and generally edit those data in the conventional way, determine which source yields the most accurate impact prediction, and display that to the range safety officer. Details of these plans are not announced at present. Basically, there is no objection to such a sophisticated procedure so long as it does not result in more severe restrictions for the vehicle—i.e., so long as the lag Δt is not increased, during which the velocity vector turn angle may accumulate yielding the Type III deviations for the construction of the destruct lines. But it appears worth while to investigate the relative merits of the two possibilties—high accuracy and large Δt versus lower accuracy and small Δt.

If the second approach were chosen, the Type III deviations would be decreased, but the Type II deviations would be increased; while in the high accuracy and large Δt case, the opposite would be true. However, it is quite conceivable that the combined contribution to the destruct line offset of the lower accuracy and small Δt approach would be more favorable. These facts should be carefully investigated before the final decision is made about the way in which the new, more powerful computer is to be used.

Thus far, telemetered on-board measurements have not been used as range safety intelligence because on-board systems are considered a priori less reliable than ground-based ones. This assumption may be justified if new on-board systems are compared with proved ground systems. But, in the course of time, considerable flight-test experience has been accumulated for various systems—e.g., attitude sensors. Thus a basis does exist for deriving a certain degree of confidence in those systems. (It also should not be overlooked that some of these systems are not peculiar to specific vehicles but have a more general application, thus broadening the basis from which confidence can be derived.) Therefore, the prejudice against the use for range safety purposes of information derived from vehicle-borne instruments should be abandoned. Comparison of such information with the predicted values and with permissible variation limits could be useful in placing the crucial decision for flight termination action on a broader basis.

In this connection it appears worth mentioning that the guidance system of any missile constitutes some kind of impact predictor, and telemetered guidance information should, therefore, lend itself to supplementing the impact predictor information proper. In case of radio guidance, no on-board information need be used; the input into the (ground-based) guidance computer can be diplexed to serve also as input for impact prediction calculation in the usual way.

Another means of reducing the lag interval Δt is given by proper combination of direct position measurements with direct velocity measurements, the latter derived from vehicle-based equipment.

It is further conceivable that some computer could continuously compare impact prediction data obtained from different, independent sources and thus display some information as to the confidence which may be placed in these data.

Detailed investigation of these various possibilities is not intended at this time. They are enumerated solely to indicate possible avenues of development.

As the ultimate development, completely automatized range safety procedures can be foreseen. This can be accomplished in various ways:

(a) By programing a computer for the decision-making process needed for flight termination action, to be based on present-type instrumentation or its updated versions.

(b) By programing a simple missile-borne computer to terminate the flight if certain critical (on-board) measurements exceed permissible variations.

(c) By simultaneous operation of systems according to (a) and (b).

The system proposed in (b) may be envisioned as something similar to the automatic abort system developed for the Mercury flights.

A word of caution, however, appears appropriate in these days when individuals shunning responsibility generally seek recourse to automatic computers for the decision-making process. In any case of automated range safety equipment, there should be human supervision by responsible individuals, well trained in and familiar with all appropriate subjects. These individuals should have the option to override, if circumstances so dictate, the decision about to be made by the automatic equipment.

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[1] Duncan, D. B., Silber, J., Searls, D., and Gross, A., *Construction of Range Safety Destruct Lines*, O. A. Working Paper No. 58-4, Oct. 1958. (Report unclassified.)

[2] *GERSIS to Insure Safety in Nike-Zeus PMR Firing*, Missiles and Rockets, March 20, 1961, p. 34.

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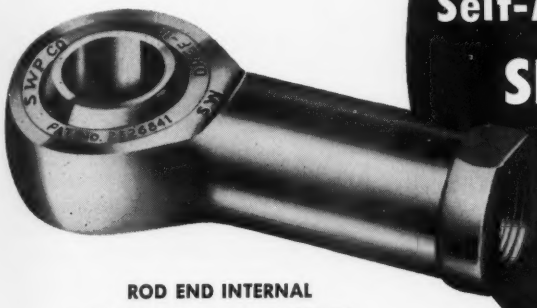

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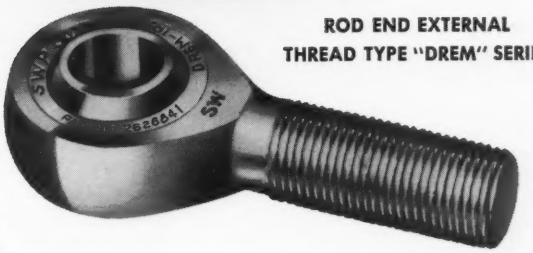

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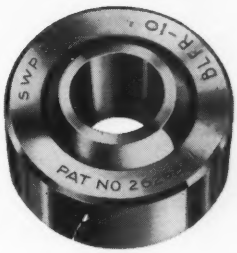

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Minuteman Missile Transportation System

(Continued from page 23)

Fig. 3. Prototype transporter-erector in erected position.

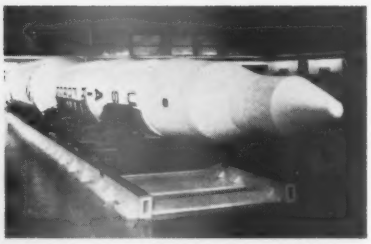

Fig. 7. Completed missile supported by engine harnesses.

Engine Harnesses

The engine harnesses have been designed to support either individual engines or the assembled missile. Minuteman solid propellant engines are designed to have a high efficiency—i.e., a high ratio of propellant weight to case weight. This presents problems in handling engines without damage. Deflection tests in several kinds of supports were conducted, and the harnesses shown in Figs. 4–6 for first-, second-, and third-stage engines were developed. For first and second stages, flexible rubber-lined bands 5 in. wide support the engines at the "wye joints" or intersection of case and end closure. A flexible full hammock supports the third stage. The flexible bands and the hammock are mounted to hinged side panels, providing automatic adjustment to engine diameter variations. The side panel and band assembly are mounted to the undercarriage by a torsion bar spring system. Hydraulic dampeners provide approximately 40 percent critical damping. The spring rate is approximately 1 in. per g. This provides the required missile dynamic suspension and permits recycling a missile without damage to interstages. Since the harnesses are a part of the payload, careful design to control weight was required. The end restraint rings shown are removed for missile assembly. The overhead restraint bands are removed prior to missile erection. The completed missile supported in the harnesses is shown in Fig. 7.

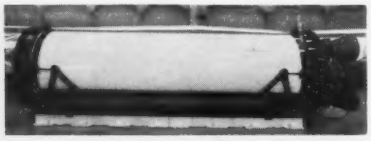

Fig. 4. First-stage engine and harness.

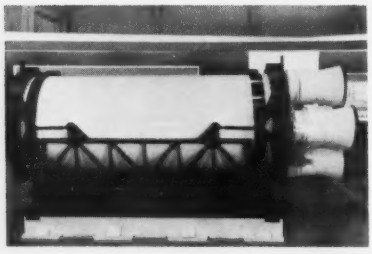

Fig. 5. Second-stage engine and harness.

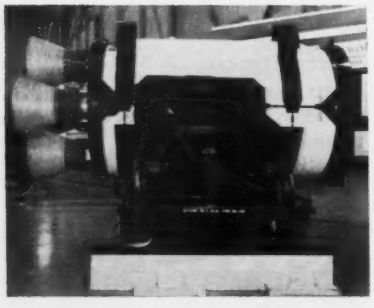

Fig. 6. Third-stage engine and harness.

Fig. 8. First-stage engine transporter and tractor.

Fig. 9. Second-stage engine transporter.

Engine Transporters

The transporters used to move the engine from the engine manufacturer's plant to the missile assembly plant are primarily for highway use. They may, however, be shipped by air or piggyback by rail.

These transporters have suspension systems compatible with the harness suspension system to limit the transmission of road shocks to the engines to not more than 3g in any direction. They are insulated and have environmental control to maintain the required engine temperature of 80°.

Because of the weight of the engine, the first-stage transporter was designed as a semimonocoque structure to obtain the lightest possible container and permit easy, over-the-highway operation. This transporter, shown in Fig. 8, has air suspension for shock control. A stand-

Fig. 10. Re-entry vehicle and guidance and control section emplacement and maintenance van.

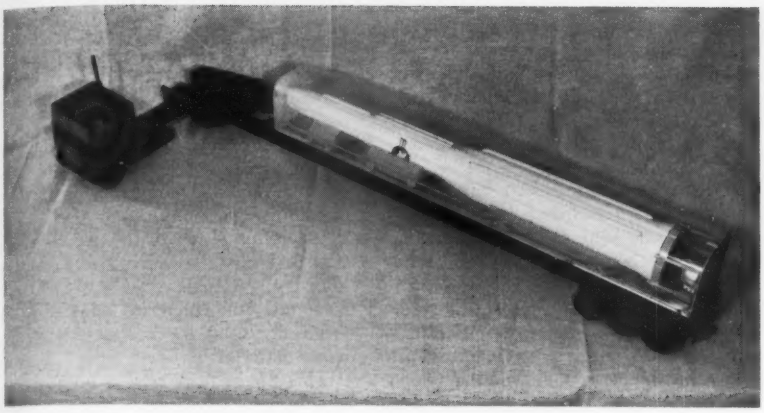

Fig. 11. Missile air transport container on semitrailer.

ard commercial auxiliary power unit, refrigeration unit, and heat exchanger provide environmental control.

The second-stage transporter shown in Fig. 9 has a standard commercial truck with soft leaf spring suspension. The commercial standard van has been modified to meet Minuteman requirements. The environmental control system is assembled from selected commercial components.

The third-stage transporter is a smaller version of the second-stage transporter shown.

Re-Entry Vehicle Transporter

Since the re-entry vehicle is not assembled with the rest of the missile at the assembly plant, equipment to transport the re-entry vehicle to the launch site and install it on the missile is provided. The transporter is shown emplacing the re-entry vehicle in Fig. 10. This specially designed transporter is approximately 25 ft long, 8 ft wide, and has a height of 12 ft. 6 in. It uses a standard Air Force tractor. The van has a trap door in the floor and is equipped with a small bridge crane. After driving over the silo, the silo lid is removed and the re-entry vehicle lowered into place through the floor opening.

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Missile Air Transport

Logistics studies have shown the need for air transport of the Minuteman missile. To accomplish this function, a strongback container called an MCAT (Missile Container Air Transport) is being developed. A model of the MCAT loaded on a flatbed semitrailer for surface movement is shown in Fig. 11. For air transport it will be rolled into a C-133 airplane. The container will have the stiffness needed to act as a strongback for the missile. The MCAT will have environmental control and can be used for missile storage. It can also be used for rail shipment of the missile.

Conclusion

These are the basic items in the Minuteman transportation and handling system. This system is designed to perform the required transportation, handling, and emplacement tasks efficiently with a minimum of hardware. Standard commercial equipment has been utilized to the fullest extent possible to reduce development costs. Qualification testing is under way and will be completed in time to support Minuteman deployment.

Space and Democracy (Continued from page 25)

the ones who man our defense operations and will be called upon to do the fighting in time of crisis with the new weapon that is so badly needed. Technology can lead us to disaster or to a more advanced civilization depending upon the results of its efforts. The State Department, right now, is engaged in disarmament talks. Our position in these talks should include the best advice ot our scientists and engineers.

The legislators of our Government also have a fair share of challenges which must be met. Because of advances in technology occurring at an ever-increasing pace, every member of Congress has the difficult task of keeping informed of latest technical developments to insure that sound programs are properly financed. Research and development is time consuming; most of the new weapon systems require 6 to 8 years from concept to deployment with trained troops. This means that legislators must appreciate fully the requirement for financing on a long-term basis, and I would hope that they pay little attention to press notices of Soviet successes since our programs are based upon careful analysis of intelligence information seldom available to the public. An item that is often forgotten is that research is not foolproof. Even with the best of talent and facilities and with adequate funding, some failures must be expected.

National Safety

A significant challenge facing legislators is to subjugate local interests for the good of our national effort.

The Department of Defense now appears to be making effective decisions earlier in the development cycle than at any time in the past. This is welcome news even though these decisions have created some minor problems in industry and in the lower echelons of the Defense establishment. I am also hopeful that in the future, the Department of Defense will place greater emphasis on establishing long-range policies and programs. With new, more-complex systems, the services need long-range project manager guidance. I think this will be remedied by improving technical management, with the best scientific advice available, at the Department of Defense level, and freeing the true scientific talent for use at the laboratory or operational level. As you all know, a good scientist who is also a good manager is a rare animal. We must leave science to the scientists and management to the managers.

Improved technical management at the Department of Defense level will assist the individual services to maintain their present level of R&D capability, and insure a minimum of duplication, not only among the services but between the services and industry.

We are a member of NATO, and for the continued success of this organization, and our other military alliances, other nations of the free world should

participate in our research and development programs. We cannot expect our allies to participate only in the production and procurement of new weapons and material that we develop. They have talent and resources which can also contribute to our common cause and the Free World has not yet reached the stage where we can afford duplication of effort in this field. We should have better joint R&D planning, so that earlier assignment of programs can be made, and so that other countries in NATO can be given responsibilities commensurate with their obvious capabilities.

Challenge to Industry

The challenges to the aerospace industry are as great and as numerous as those I have discussed for Government. In issuing these challenges, I realize that the prime interest of industry is one of making money for the stockholders. As an industrialist of 25 years' experience, I can sympathize with this problem. However, as a citizen I feel that the problem should be one of how can industry help our Government continue as a democracy.

I suggest that industry should concentrate more on programs and policies with sound technological possibilities which have profitable present and future commercial significance.

Let me illustrate this thought with one example. Our space and atomic energy programs are under Government funding and participation and without apparent possibilities for immediate profit or return. For several years many companies undertook programs in the space and atomic areas which were glamorous but had little potential or opportunity for real sound business. The total profits and losses for the companies who went into atomic energy probably still add up to a net loss. However, those who survived had good technical management planning and faced each new decision with a sense of reality. Therefore, may I offer this advice—Don't try to go into the space field unless your programs are basically sound—sound for the country and sound for future commercial peacetime business.

A clear-cut example of a space program that has immediate and long-term potential for both civilian and military application is the development of satellites for world-wide communications. Within the Government, the agencies concerned with this program include ARPA, DOD, NASA, FCC, and Commerce. The Army has the principal R&D effort in the development of a communications satellite and has the experience and management competence to make certain that the urgent military needs for an increased communications capability are met with satellite systems. In my view, a communications satellite offers for the entire world the most interesting space application for years to come. It is obvious to me that a long-range program directed toward world-wide operation is possible and desirable.

Satellites for military or civilian communications are almost indistinguishable in terms of research and development requirements and their design and operating characteristics. The NASA Rebound and Relay and the current Army ADVENT communications R&D programs are essentially identical in their early phases; but neither fully reflects, in terms of funding or program time, a truly global, active operating communications satellite effort. Communications satellites for the next few years will be limited to the research and development type but ultimate success will require increased reliability, extensive ground facilities, and considerably more operating experience than is available at present. The Government has experience, facilities and logistical support essential to a global communications satellite program. Industry has the scientific talent and facilities to develop and operate such a system. Together, Government and industry can finance the R&D phase of about $200 to $300 million and provide the total investment of more than $500 million needed for a new successful operational system for world-wide military communications. As for the nonmilitary communications, the use of world-wide communication satellites with wide bandwidths will have tremendous significance in terms of international relations and international cooperation and can do more to establish the United States as a leader in space than any other project I can name.

The annual commercial revenues of this program could easily reach several billions of dollars per year by the late 1970's. Just visualize the possibilities of a system that permits person-to-person dialing throughout the world and world-wide television facsimile programs. Such an enterprise offers more commercial possibilities than reaching the moon, even though an American station on the moon will help our country's prestige. To do this, industry should close ranks and form a joint corporate team to explore and develop the possibilities. Industry can take the lead in this matter, and not wait for more Government funding and leadership. After all, most of the resources needed have already been paid for by the Government. All that is needed is some management with vision to establish the programs.

Using Results of Defense R&D

I have singled out this one possibility that I think is now ripe and ready for industry. There are probably many others, if the problems are examined closely. In short, I think industry should consider leaving the military assignments to the Department of Defense, and devote more effort to finding means of using the results of military research and development for civilian or commercial application.

We are all aware of the real competition that exists today in the aerospace industry. Actually, industry has more personnel and facilities than can be profitably used for production of defense material in peace time. You in the aerospace field have a unique contribution to the cause of peace. I will merely pose the question "What do you propose to do, or should our Nation do, with the tremendous build-up of people, facilities and talent in our aerospace industry when peace—not war—breaks out?" This is not an idle question but one that all of us concerned with disarmament must face now.

I feel strongly that industry has a real challenge. The only possibility I foresee for expansion in the future is through civilian or commercial application of potentials such as I have just outlined.

The time has come when all segments of our society must face reality brought by the changes in technology, and develop a true appreciation of the new role of research and development in determining the course of our civilization. The industrial revolution progressed at a snail's pace in comparison with the changes this generation is witnessing. This research and development revolution means that now our fiscal policies, strategy and diplomacy are being determined by our technological capabilities. In short, our future now rests as much in the hands of engineers and scientists as it does in the hands of the liberal-arts graduates. Good or bad, this is occurring and we might as well face reality and accept the challenges ahead. The survival of free enterprise depends upon how well we plot our course.

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Site Planning Facilities Support

(Continued from page 27)

techniques are worth the application.

These three criteria identify six basic areas of individual problems and hence are a part of the overall method used here. Each of the six problem areas permit the application of mathematical analysis and thus are used as examples of the techniques. By application of the analysis technique, each is redefined individually, thus producing a satisfactorily clear picture of exactly what each problem is, what results can be expected, and whether the problem is truly a valid one for this type of analysis.

There should be no expectation that the use of the mathematical techniques can provide actual designs, master plans, structures, buildings, or any such ultimate requirement. Rather, they can be depended upon to point out the unacceptable solutions. In no case are they considered as replacing the designer as such, but only as an additional tool for his use. This should be obvious, but cannot be overstressed.

In accordance with the three criteria listed above, the following problem areas are those typically encountered in a majority of the larger projects and in many smaller ones handled by the architect-engineer:

Problem area 1: The site (master) planning overall layout.

Problem area 2: The two-dimensional (sometimes three-dimensional) space relationships of *all* structures, buildings, roads, etc., *one to the other*, in a complex or large facility.

Problem area 3: The *optimizing of location* or the space relationships of a *single* structure to one or more other structures for specific reasons. (These "reasons" must usually be taken one at a time in analyzing such space relationships.)

Problem area 4: The *optimization* of any *one desired requirement* or *function* of the complex or individual unit —e.g., "safety," "cost," "convenience," etc.

Problem area 5: The (financial) overall controllable *costs considered as a mathematical* function vs. the time to construct or complete the project under consideration.

Problem area 6: The "*minimization*" *of specific features* such as minimizing of hazard vs. location—e.g., a reactor or a noise-reduction requirement or the elimination or avoidance of toxic fumes from an emitting source, the parking and traffic problem where this creates "interference" or "objection" from other units in the facility or complex.

In connection with the sixth problem area, the cost of utilities in large installations is often very high. Thus, it is valid to attempt to minimize these via the location of buildings. Similarly, the attempt to minimize the required travel or traffic time between two or more structures is valid, both for economics and for convenience. Many other space relationships which benefit by the minimizing of some portion of the planning concept readily come to mind.

"Minimum" as used here is not necessarily the *shortest distance* obtainable between two points. Rather, it is optimum *balance* of several practical and acceptable "minimums" according to project needs.

Illustrative Problems Developed

Two problems are developed in detail. Example 1 illustrates two of the six problems already mentioned—the overall relationships of all buildings (problem area 2) combined with optimization of a single building location (problem area 3), both of which lend themselves to linear programing techniques.

Example 2 illustrates the minimization (of costs) in satisfactorily locating two associated structures so that utilities, roads, tunnels, etc., are held to minimum expenditures applicable to overall cost considerations, as was suggested by problem area 6.

Example 1

This example presents the means of locating a specific building, given the following specific assumptions:

(a) Assume here a large (existing) military base complex with many existing buildings on it, but with eight major "areas" which a new building must serve.

(b) Assume also, because of topography and other developments, that there are only four remaining locations that can be considered for this new building.

(c) Assume that the new building will serve *all* the persons daily in all eight areas.

The problem then is to determine which of the *four* possible locations will serve *all* of the people, in *all* of the eight areas of population, in the *best possible fashion*. For simplicity, the new building is also assumed to cost the same, no matter where it is located among the four different available sites.

Solving the problem then should give the location which will minimize the *sum of the total* "travel time" consumed by all the persons using the new facility. (Note that while this problem illustrates "techniques," it is obvious that this is by no means the only problem connected with "location.")

Chart A shows a diagrammatic scheme of a site of perhaps 5,000 to 7,500 acres with the eight existing areas (or subcomplexes)—designated Areas I through VIII—and the four possible locations for the new building—designated Y1, Y2, Y3, and Y4.

Chart B restates the problem and indicates symbols for the equation.

Chart C represents the consumed time (or it could be a "cost" if "travel time" is paid for through employee salaries).

In Chart D, T represents a "weighting factor" and, as used here, the number of persons in each of the eight areas. The numbers in each area are determined by a census count or a prediction of the population per building, or as known by the administration of the facility.

Letting x to Y represent the measured distance in feet ("yards" or "time") from Areas I through VIII to each of the four possible new building locations Y1, Y2, Y3, and Y4, multiplied by the

Chart B.

The problem:

To determine which of four permissible locations will minimize the sum total of travel time (and distance) for all persons served by the new Y facility—i.e., total travel time consumed by all

where

C	=	consumed time
T	=	weighting factor (number of persons in each of eight areas)
$(x \leftrightarrow y)$	=	measured distance (ft, yards, or miles), Areas I through VIII (x's) to each location, Y1 through Y4 (y's)
x	=	center of each area (I through VIII) for measurement to Y locations (Y1 through Y4)

Chart C.

The four iterations y will use the expression:

$$C = \sum_{i=1}^{n} T_1 \, | x_1 - y | \begin{cases} \text{represents a summation of all the} \\ \text{conditions and/or magnitudes of the} \\ x\text{'s to } y\text{'s} \end{cases}$$

This expression gives a compilation and comparison of distance from the eight separate areas to the four possible Y locations and also indicates the optimum location.

weighted T factor for populations, gives the compilation of "travel time" for the eight separate areas to the four possible new site locations as shown on the tabulation of Chart D.

Column I identifies the eight areas. Column II identifies the number of people ("weighted factor") T as T for each area, using 2 for 200 persons, 5 for 500, etc. Column III represents the four possible locations Y1, Y2, Y3, and Y4 with the distances from each Area I through VIII (above the slant line) to the locations of Y1 through Y4. Thus, Area I has 14 in the upper corner representing 1,400 ft from Area I to location Y1. Similarly, for Y2, 8 or 800 ft; for Y3, 10 or 1,000 ft; and for Y4, 12 or 1,200 ft.

Figures below the slant line for the corresponding locations are 28, 16, 20, 24, representing the distances multiplied by the T factor—i.e., in the first column, Y1 equals 200 persons times 1,400 ft, or 2 times 14 equals 28; and the second for Y2, 2 times 8 or 16; Y3, 2 times 10 or 20; and Y4, 2 times 12 or 24.

The bottom line sums up the multiplication of T factors times the distances for Y1, Y2, Y3, and Y4 and gives the sums of the total travel distance for all persons and thus the location which provides the minimum condition for travel—which is Y3.

The computer is helpful in carrying out very large site problems. Most of the smallest general-purpose computers easily handle this type of problem. The present availability of computers makes it reasonable to use these mathematical techniques for such tasks as analyzing site planning and other architectural and engineering problems. Without these, the tedium and time involved in solving hundreds of equations could hardly be justified.

Example 2

Charts 1 through 5 present the second problem, a "minimization of costs" as applied to site/master planning.

A major problem in site planning is the relationship of one specific structure or installation to a second specific structure. Here, costs directly related to the placement of the buildings become a powerful influence. Often, for example, safety, shock or vibration, toxic fumes, explosives, noise, etc., become factors of utmost importance. The mandatory control or accommodation of these invariably involves serious cost considerations.

The example problem suggests an unknown distance for the separation between two structures which must be determined from an optimum standpoint (or "proximity distance" which is an optimum). In site planning, there is usually a compromise in the distance or separation between companion structures because a "separation distance" may be reduced, for example, at the expense of either strength, safety, soundproofing, or whatever else will allow a reduced separation distance. What is sought in this problem is the optimum distance or separation that entails a minimum of cost from all aspects. Note that this example confines itself to cost.

A typical situation is one in which two buildings, B-1 and B-2, must be separated from each other by some undetermined distance X. It is assumed that the buildings bear a relationship so that communications, power, corridors, tunnels, and other utilities and services must be connected between them. A second assumption is that B-1 is the "source of trouble" to B-2 (or B-2 is the "recipient"). It is also assumed that the cost of constructing B-2 varies inversely with the distance from B-1 because of the reduction in the trouble that is provided by separating B-1 from B-2. Here a reactor ("experimental") is "assumed" to be a possible source of hazard to its associated laboratories in case of accident. Thus, the farther B-1 is from B-2, the fewer are the special safety measures or structure elements required around the reactor building.

In general, connections, communications, roads, tunnels, power line costs, etc., vary directly with the distance they are required to run. Therefore, with cost information on these items, it is possible to set up a cost equation which can be minimized, thus providing the solution for an optimum *separation distance measurement* based on cost relationships alone.

Chart 1 illustrates the two buildings, with the reactor building B-1 shown as a source of trouble to the laboratories B-2 because of possible accidents, hazards of radiation, etc.

Chart 2 lists facts and symbols for the equation and includes the two arbitrary "safety cost" figures C_b and C_w. The reactor building B-1 is given as "source of hazard."

In the cost equation, let

C_r = cost of roads per mile between buildings B-1 and B-2

C_c = cost of communications, telephones, etc., per mile between buildings

I	II "T"	III			
AREA Nº	PERSONS IN EACH AREA (HUNDREDS)	Y_1	Y_2	Y_3	Y_4
		DISTANCE / T × DISTANCE	DISTANCE / T × DISTANCE	DISTANCE / T × DISTANCE	DISTANCE / T × DISTANCE
I	2	14 / 28	8 / 16	10 / 20	12 / 24
II	5	13 / 65	8 / 40	8 / 40	10 / 50
III	4	8 / 32	7 / 28	3 / 12	4 / 16
IV	2	7 / 14	7 / 14	2 / 4	2 / 4
V	6	6 / 36	3 / 18	2 / 12	4 / 24
VI	1	7 / 7	4 / 4	8 / 8	9 / 9
VII	5	5 / 25	8 / 40	10 / 50	10 / 50
VIII	10	8 / 80	15 / 150	12 / 120	10 / 100
$C = \sum_{i=1}^{n} T_i \lvert x_i - y \rvert$		287	310	266	277

OPTIMUM LOCATION ∴ Y_3

Chart D.

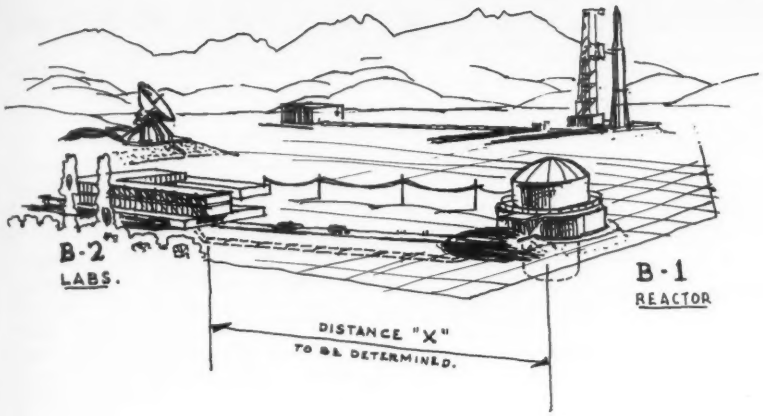

Chart 1.

roads, communications, and power, the mathematics of the equations is reduced to "miles." The solution as indicated gives "2 miles" as the "optimum," minimum distance for this hypothetical problem.

Chart 5 shows the curve of plotted values of X as a function of the costs.

The costs begin to diminish immediately upon separating one building from another, and drop, as shown, for the first 2 miles only. With greater separation, costs of the utilities begin to overcome the costs of the safety features, and the curve rises and will continue to rise since utility costs, such as used here, are essentially in direct ratio to the distance run. Therefore, little or no

C_p = power cost per mile between buildings

C_b = cost of B-2 (labs) being located near B-1; an arbitrary amount of additional cost of providing safety and shielding for every mile that B-1 is located closer to B-1; C_b is therefore here measured in dollar miles

C_{b_0} = cost of B-2—that is, the labs—assuming that no extra safety costs are required; again arbitrary and measured in dollars (as an assumed lump sum)

X = separation distance between B-1 and B-2

C = total cost of B-2, plus additional costs required by "optimum" distance (as determined to minimize this total cost C)

Chart 3 gives the cost equation with total cost noted as C. Chart 3 also provides unit cost data from our A-E office files (or "arbitrary," as noted above) for substitution in place of C factors [see (5) below] and completion of the solution, as follows:

(1) Cost of roads, C_r, approximately $20,000 per mile.

(2) Cost of communications, C_c, approximately $2,000 per mile.

(3) Cost of power lines, C_p, approximately $3,000 per mile.

(4) Arbitrary cost, C_b, for safety features required in B-2, a lump sum of $100,000.

(5) Overall cost, C_{b_0}, of B-2 with no extra safety costs required regardless of location, $400,000.

Chart 4 gives one method and formula for substitution cost coefficients. Other ways will come to mind for use of these factors in determining the optimum distance for X as related to minimum costs. We apply calculus, perhaps the simplest method for this case with the minimum cost when d/c over d/x equals 0. Using the two "arbitrary" costs and the three substitutions for

Chart 2.

Equation factors for minimum cost distance:

B-1 = reactor building (hazard source)
B-2 = laboratory (hazard receiver)

where

C_r = cost of roads (miles)
C_c = cost of communications (miles) } between
C_p = cost of power (miles) } B-1 and B-2
C_b = cost of B-2 being located near B-1; e.g., safety costs or structure costs (measured in dollar miles)
C_{b_0} = cost of B-2, assuming no extra safety costs (measured in dollars)
x = separation distance, between B-1 and B-2
C = total cost; B-2 plus all costs above

Chart 3.

Cost equation:

$$C = xC_r + xC_c + xC_p + C_b/x + C_{b_0}$$
$$= x(C_r + C_c + C_p) + C_b/x + C_{b_0}$$

To complete solution, use:

Cost coefficients (from A-E "building cost" data files):

C_r = \$ 20 × 10^3/miles = \$ 20,000/miles (roads)
C_c = \$ 2 × 10^3/miles = \$ 2,000/miles (communications)
C_p = \$ 3 × 10^3/miles = \$ 3,000/miles (power)
C_b = \$100 × 10^3/miles = 100,000 dollar miles } arbitrary for problem
C_{b_0} = = \$400,000

Chart 4.

Minimum cost; using calculus as the simplest method

where

$$dc/dx = 0$$
$$dc/dx = (C_r + C_c + C_p)(-)(C_b/x^2) = 0$$
$$x = \sqrt{\frac{C_b}{C_r + C_c + C_p}}$$

Substituting (values from Chart 3):

$$x = \sqrt{\frac{100 \times 10^3}{(20 + 2 + 3) \times 10^3}}$$
$$x = \sqrt{\frac{100 \times 10^3}{25 \times 10^3}} = 2 \text{ miles}$$

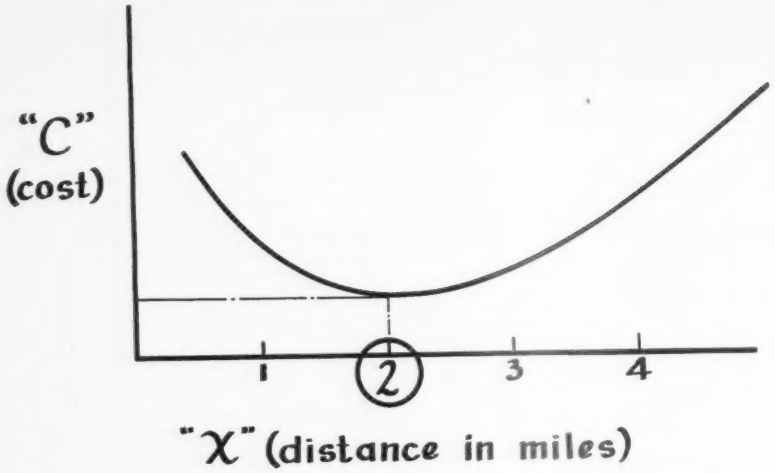

Chart 5. Minimum (cost) distance; plotted values of x (distance) as a function of C (cost).

change in the straight-line curve should be expected.

Conclusion

What is accomplished by these techniques? DMJM's answer would consist of what we have found by our use of them. Specifically we note:

(1) They provide a means whereby we can determine in advance why one solution, one location, or one decision is appropriate and for what reason. Whether or not a particular solution is used is not in itself significant. Other things may override any particular answer arrived at by mathematics, but a *method* of getting at solutions or answers is significant.

(2) Subtle, major errors can be detected in advance of actual planning, thus permitting corrections to be considered, using (again) the mathematical approach.

(3) Definite determination of suitable "maximums" and "minimums" for an infinite number of different situations can be tried and pretested.

(4) The optimizing—or minimizing, as the case may be—of other types of functions which lend themselves to the mathematical approach can be applied to planning analysis through these techniques and associated mathematics.

It should again be stated that this is an *analytical effort*, a tool to aid the planning problem. These mathematical techniques for planning are applicable now because of the computer. Their use would not be appropriate without the computing equipment which provides rapid solutions to the many equations useful in planning, and the equipment is essential for more complex problems than those shown here. Quite properly, the more equations required to be solved, the more appropriate it is to use computing techniques and equipment. Beyond this, it is strictly up to the ingenuity of the planner/programer.

The Hazards; What This Cannot Do

To use these techniques without realizing the hazards involved would be not only foolish but dangerous to planning. These techniques cannot create concepts, designs in architecture, or "good planning." But they *can* help. A final caution—none of this type of effort should be entrusted to those who have less than 5 to 10 years of experience in planning, except as checks on their own work.

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Hose Material Compatibility With Freon 114 (Continued from page 29)

that it would not in any way interfere with the function of the system.

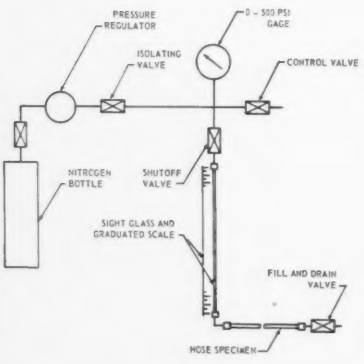

Fig. 2. Apparatus for measuring leakage of Freon 114 from hose specimens.

The decreasing rate of permeation for Teflon shown (Fig. 3) suggests that a hose freshly exposed to Freon experiences rapid absorption of the fluid until saturation condition is reached, after which no additional Freon is retained in the hose material. After an initial transient, the Teflon hose had a nearly constant leakage rate of only 0.0015 $in.^3/hr/ft$.

Conclusions

It was felt that the Teflon-lined hose had a slight negative factor when considering its use because of this permeability but, its other characteristics, such as its ability to transfer Freon without contamination, its ability to be cleaned suitably for the environmental extremes in which it is to be used, and its availability make it the most suitable hose for use on the prelaunch cooling system support equipment.

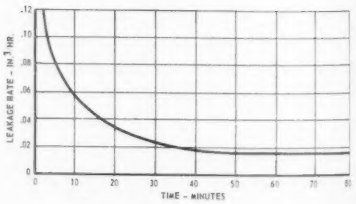

Fig. 3. Leakage rate of Freon 114 from Teflon-lined hose—1/4-in. line size, 120 in. long. Fluid pressure 125 psig.

The Mini-Recorder System *(Continued from page 33)*

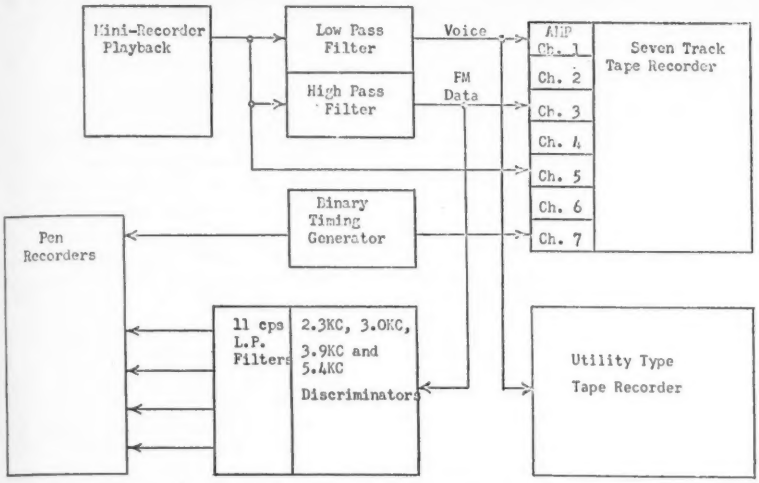

Fig. 3. Block diagram of method used in postflight ground playback.

functions, as well as voice information.

Description and Operation

A block diagram of the Mini-Recorder system is shown in Fig. 1. In a simple and straightforward system for converting data to be recorded on magnetic tape, the input signals are converted into a usable form (frequency modulation of carrier signals) for recording onto the tape. The unique feature of the system is the adaptation of a small, portable, office-type battery-operated tape recorder for this purpose. The recorder selected is a transistorized, self-contained, single-track unit $8^1/_2$ in. by $3^7/_8$ in. by $1^7/_8$ in. in size. Cartridges of 1/4-in. mylar tape are used. The half-width head records one track on one half of the tape width; reversal of the cartridge permits recording on the remaining half of the tape width. At a tape speed of 3.75 in. per sec, total recording time is 22.5 min on each tape track, for a total time of 45 min per cartridge. Usable frequency response is 50 to 10,000 cps (100 to 8,000 cps at ±3 db).

This portable tape recorder is modulated by a $2^3/_8$ in. by $2^3/_4$ in. by 5 in. unit containing four plug-in voltage-controlled transistor subcarrier oscillators and data converters, a power regulator, a 1.0-kc low-pass filter for the voice signal, and all necessary interconnecting wiring. The voltage-controlled oscillators have output series isolation resistors within the plug-in chassis; their output terminals are connected to the filtered and attenuated voice signal to be mixed and fed to the recorder amplifier. Standard IRIG subcarrier channel frequencies of 2.3, 3.0, 3.9, and 5.4 kc with the standard full-scale deviation of ±7.5 percent are used.

The inputs to the voltage-controlled oscillators are passed through a test plug; +28 volts, regulated to +6 volts, and ground leads are brought to this plug. Removal of the test plug disconnects the oscillator inputs and allows the introduction of precise voltage inputs for calibration.

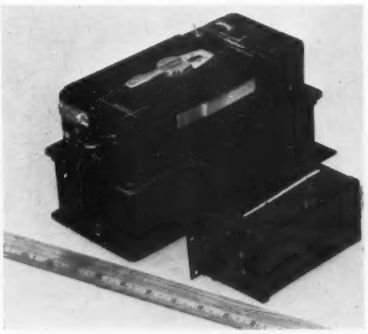

Fig. 4. Tape recorder, data converter unit, and mounting bracket.

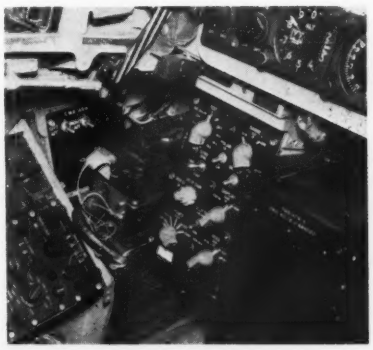

Fig. 5. Mini-Recorder system installed in radar operator's cockpit of F4H-1 aircraft.

Two of the oscillators are fed d.c. inputs which vary relatively slowly (closing velocity and range to target). The other two are fed step changes in d.c. level to indicate time occurrence of various fire-control functions. The step voltages are combined in data converter units for driving the voltage-controlled oscillators. Fig. 2 is a circuit diagram of the individual data-converter circuits.

The block diagram of Fig. 3 shows the procedure used for playback. The tape is played back on the Mini-Recorder for convenience in handling the tape cartridges, and is re-recorded. The voice only is recorded on a utility recorder for use in debriefing conferences, and is also recorded on one track of a standard seven-track recorder. The mixed FM signals, less the voice, are recorded on another track, and the total signal (voice plus FM signals) on a third track. Binary timing is recorded on a fourth track. This timing signal is not related to the real time of the operation, but is used for convenience in correlating events during any further study of the seven-track tape. The FM signals are also fed to a bank of discriminators and filters, where the recorded data are detected and passed through 11-cps low-pass filters (to eliminate flutter noise), and then to pen recorders.

A view of the Mini-Recorder unit is shown in Fig. 4. Fig. 5 shows the Mini-Recorder installed in the F4H-1 aircraft.

Analysis of Performance

The battery-driven tape transport uses a centrifugally actuated switch for capstan speed control. This introduces a slight speed variation centered around 20 cps. The specified maximum flutter for the tape transport is ±0.3 percent. The mechanism operates within this specification, but, using the transport for both record and playback, the re-recorded signal has a flutter averaging about 0.5 percent. This is ±7 percent of the full-scale deviation range of ±7.5 percent of the carriers. Since the flutter is centered around 20 cps and contains practically no components below about 15 cps, it can be eliminated by the use of 11-cps low-pass filters at the discriminated data outputs. The analog data recorded on two of the carriers are slowly varying functions requiring a bandwidth of not more than 8 cps; the step functions recorded on the other two carriers need be defined in time to only about ±40 millisec. Therefore, the use of the 11-cps low-pass filters does not degrade the data. Two events occurring as close together as 20 millisec can be separately identified on the oscillograms. Examples of oscillograms made on playback of the Mini-Recorder are shown in Figs. 6 and 7.

The voice channel is somewhat lacking in fidelity because of the 1-kc upper fre-

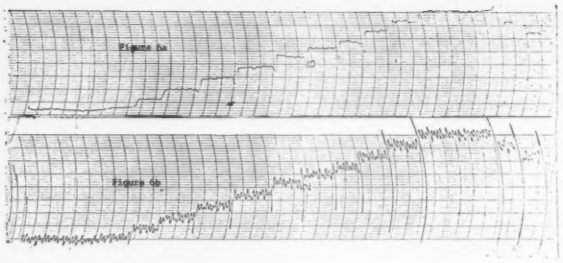

Fig. 6. Result of a 5-volt step calibration fed to the Mini-Recorder, played back, discriminated, and recorded by a pen recorder. (a) This calibration when an 11-cps low-pass filter is used at the output of a discriminator. (b) Effects of using a 25-cps filter.

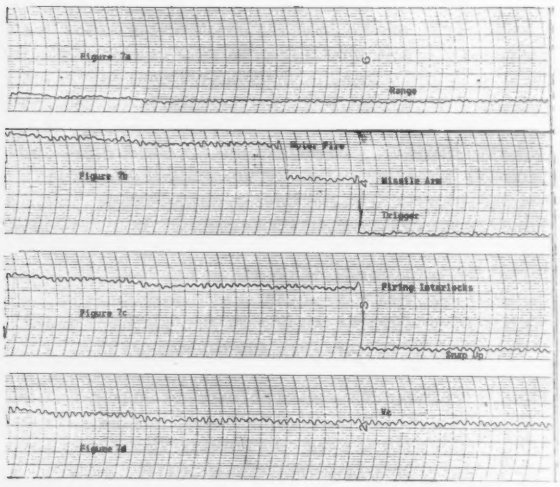

Fig. 7. Record of the F4H-1 data functions recorded on the Mini-Recorder and played back through discriminators with 11-cps low-pass output filters. (a) Recording of the range to target voltage. (b) Summation of firing circuit voltages where first the trigger voltage is indicated, then the missile arming voltage, and finally the missile motor fire voltage. (c) Firing-circuit interlock voltage and a voltage indication called "Snap-Up," a computer function voltage. (d) Recording of the closing velocity (Vc) of the aircraft to target.

quency limit, but it is distinguishable.

For some flight tests, greater flexibility in setting up input data to be recorded and additional data-recording capacity are needed. For these reasons, a revised prototype model is being constructed. The low-pass filter cutoff frequency for the voice channel has been increased from 1,000 to 1,500 cps, with a sharper cutoff, to improve the readability of the voice recording. A fifth voltage-controlled oscillator, at 7.35 kc ± 7.5 percent, has been added. Plug-in input data converter units allow flexibility in selection and connection of input data to be recorded. Fig. 8 shows the complete unit, without the tape recorder. The recorder will be mounted on top, as in the original model. In Fig. 9 the cover has been removed. One of the basic data-converter shells is shown on top of the unit.

Recommended Modifications of Recorder for Improved Operation

For the flight tests for which the Mini-Recorder was designed, a maximum required data bandwidth of about 8 cps was sufficient. For recording data of a higher frequency rate, an improvement in the flutter characteristics of the tape transport must be made. Some improvements to the recorder can be made by replacing the capstan bearings and the motor drive belt with substitutes, and by mounting an additional flywheel on the capstan. However, such modifications do not affect the basic flutter frequency of 20 cps, the amplitude of which is even lowered somewhat by the added flywheel. The added flywheel must extend above the top surface of the recorder, increasing the mounting space required, and must be removed to replace or turn over the tape cartridge. The full 45 min of recording time was required for the flight operations of the F4H-1 installation, necessitating an arrangement which permitted the radar operator to remove and replace the tape cartridge in flight.

The flutter of the tape transport may be reduced significantly by the use of a d.c. driving motor governed by a tuning fork or by a balance wheel-escapement system; either modification might require a nearly complete redesign of the tape transport. The effect of flutter may also be reduced by utilizing one of the voltage-controlled oscillators as a reference frequency source, the discriminator output from this reference—on playback—being subtracted from the data discriminator outputs, thus canceling the flutter noise on the pen recordings.

If additional data-recording capacity is needed, a second magnetic recording head may be added for recording on the other tape track. Additional voltage-controlled oscillators, amplifier, and circuitry for inputs and for mixing of carriers would need to be provided. The total recording time per tape cartridge would also be cut in half. The use of a dual-head, four-track system similar to the standard four-track stereo sound system would provide two tracks of recording for the full 45 min. The reduced signal-to-noise ratio resulting from the narrower tracks would have to be considered in planning for any particular application. In any plan for increased data-recording capacity, the basic requirements of small size and light weight must be kept in mind.

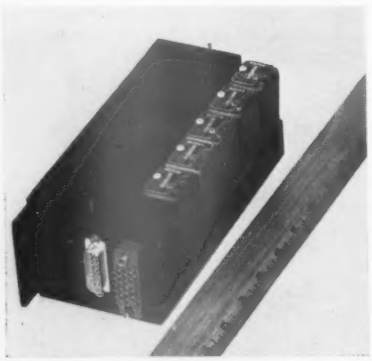

Fig. 8. Improved data converter unit near its final stage of construction.

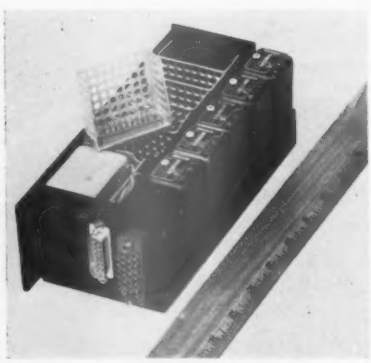

Fig. 9. Improved data converter unit illustrating individual data subchassis units.

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Missile Silo-Storage Corrosion

(Continued from page 35)

Table 1. Corrosive Agents in Rain Water[17]

Compound and Source	Location	Concentration (mg/l*)
Chloride, Cl^-; major source is sea spray	Over sea or near coastlines	Average 2–20; with extreme winds may increase up to 100
	500 miles or more inland	Average 0.1–0.2 but sometimes higher than 1.0
Sulphase, SO_4^{--}; major sources in industrial areas	Large cities, industrial areas	Average 10–50; higher under extreme conditions—i.e., smog
	Other areas	1–5
Nitrate, NO_3^-	Over land	0.5–5
Hydrogen ions, p^H	Over land	Average around 5; near industrial centers it may decrease to 3

* Concentration in rain water in milligrams per liter of some of the most important constituents with respect to corrosion.

lurgical transformations, as well as corrosion. Of these problem areas, corrosion is probably the most difficult to manage because the specific conditions of storage often greatly affect corrosion rates. These specific conditions must be known; their importance must be realized in proper context.

There can also be internal sources of deterioration, such as the gradual degradation of lubricants, desiccants, and other chemicals. Missile engineers cannot dismiss the problem by counting on others who are responsible for the silo construction to produce a "perfect" environment. It is more realistic to recognize that the prevention of deterioration of the missile will require the combined efforts of all concerned. The principal considerations are to keep deterioration to a minimum and to determine accurately when deterioration has reached a point where the missile's reliability has been appreciably reduced.

The Silo Environment

Moisture Intrusion

A silo is essentially a cylindrical, steel-reinforced concrete hole in the ground. This 80- to 100-ft-deep cylinder is surrounded by earth with varying moisture content. There are several approaches to moistureproofing, and many modern methods of coating concrete and steel must be explored.

Temperature changes and introduction of outside air will result in the collection of a certain amount of moisture, and established engineering data must be used to anticipate the degree of moisture due to breathing and to calculate the amount of water vapor that will enter. Information of this type is available in the form of reports on work performed by the U.S. Navy in the postwar ship-mothballing program.

Normal sealing will not prevent the entry of water. The silo cover will, of course, require a watertight seal to prevent rain water and melting snow from penetrating the interior in appreciable quantities. The problem is aggravated by the amounts of alkalies leached by water from the soil. Acid-type infiltrations would be equally undesirable. If only a minor trickle of water is permitted to enter an area, enough of it may accumulate to cause eventual breakdown of the dehumidifying system. Corrosion will, of course, start promptly. Table 1 presents a list of corrosive agents found in rain water.

Table 2. Factors in Environmental Control and Monitoring of Silos

Protection Required	Detection Methods Required	Protective Techniques
Water	Visual inspection	Waterproofing by coatings and applications
		Drains and sump pumps
Fumes	Mine atmosphere analysis techniques	Venting and/or blowers
Humidity extremes	Relative humidity measuring devices	Molecular sieve method
		Dehumidifying systems (mechanical or chemical)
Temperature extremes	Temperature recorders and indicators	Air conditioning and/or cooling and heating from central source
"Live" environment (fungus, bacteria, insects, rodents, etc.)	Culture slides or similar method of inspection	Ultraviolet lamps and periodic extermination
Corrosion	Corrosometer (visual and/or electrical, with remote monitoring)	Protective coatings Conditioned environment

Probable Natural Silo Environments

Underground envelopes 80 to 100 ft deep typically show temperatures approximately equal to the yearly average air temperature at the surface. High relative humidities and cyclic condensation of moisture occur at depths affected by the above-ground temperatures. Severe thermal gradients can exist in motionless ambients, resulting from equilibrium when the silo cover is shut. An open silo, of course, will alter these environments to approximate the atmosphere conditions above ground. U.S. Bureau of Mines studies have determined that the average temperature of a number of underground sites between 50 and 400 ft deep is approximately 55°F. Other estimates of silo temperature irrespective of location, at a depth of 75 ft, range between 40° and 55°F. In addition, it can be anticipated that the temperature from the surface down to approximately 35 ft will average the mean annual temperature at the given site. For the United States generally, this will vary between 40° to 70°F.

Probable Silo Humidity Values

It can be safely estimated that relative humidity at the silo bottom will exceed 80 percent without conditioning. An average relative humidity of 86 percent in underground mines between 50 to 400 ft deep has been reported by the Bureau of Mines. This means that between 2.17 and 7.75 grains of water per cubic foot of air will be present at these temperatures and relative humidities.

Other Deteriorates

Fungi may be expected in an unprotected silo since the natural environment is particularly favorable to their growth. Similarly, bacteria will find conditions ideal for growth in a natural silo atmosphere.

The normal silo environment is also especially favorable to insects of all types, and rodents. It may be noted with interest that certain species of beetles are capable of boring through concrete, and that rats and mice can undermine or destroy outright certain items such as wiring and connectors.

Table 3. Effect of Sensitization and Sigma Phase Formation on the Ductility of Stainless Steels[18]

Sensitization*

301, 302, 304, 308, 309, 310, 314 — Steels Affected, Unstabilized — Become brittle at low temperature and lose corrosion resistance

316, 317, 321, 347 — Steels Unaffected, Stabilized — Remain ductile at low temperature and retain corrosion resistance

Comparison of Impact Strengths of Annealed and Sensitized 302 and 347

Type	Condition	Energy Charpy Keyhole (Ft-Lbs) 300°K	170°K	76°K
302	Annealed	79	71	66
302	Sensitized	83	43	12
347	Annealed	65	—	68
347	Sensitized	61	—	66

Sigma Phase†

Steels Affected: 303, 309, 316 — Low ductility at low temperature; 317, 321, 347 — Slight loss in corrosion resistance

Comparison of Impact Strengths of Annealed and Sigmatized 316

Condition	Energy Charpy Keyhole (Ft-Lbs) 300°K	76°K
Annealed	68	62
Sigmatized	45	26

* Temperature range 750°–1,650°F (required for formation).
† Temperature range 1,350°–1,650°F (required for formation).

Internal Atmospheres

Fuels give off vapors, and lubricants deteriorate slowly to produce lighter hydrocarbons as vapors. There may be other equipment within the silo, in addition to the missile, which would provide a source of corrosive atmosphere, either through gaseous products or through contact. There may be leakage of hydraulic fluid or, in the case of storable liquid propellants, drippings from lines, leads, tanks, etc., which will affect various parts of the missile system.

Fumes may emanate from hydraulic fluids, decomposition of solid fuels, or from any hydrocarbon materials used in the missile, including lubricants. Corrosive fumes may be generated by the slow deterioration of rubber compounds or dry film-type lubricants containing molybdenum disulphide.

The solvent fumes would have a weakening effect on any rubber or plastic products used in the missile, unless materials were specifically picked that were resistant to such fumes. An important consideration is the effect of solvent fumes on lubricants. Fumes could initiate a washing action, or at least change the lubricating qualities.

Integration of environment, not the absolute environment at any given moment, is the primary consideration. If, for a brief period, a high concentration of solvent vapor occurred within the silo, stripping or weakening of the protective coatings could occur throughout the missile. At a later time, a moisture level which could have been easily counteracted by sound protective coatings could cause damage in the areas where impairment of the coatings has been extensive. The silo atmosphere is essentially the area outside the missile itself, but various parts within the missile create small environments of their own. They must be evaluated on the basis of gaseous compounds that might be exposed.

Fumes need not fill the entire silo chamber to create the problem. The source may be in close proximity to components that are particularly susceptible to damage from fumes. The corrosive vapors or gases may affect electrical, electronic, or electromechanical parts if they manage to penetrate their protective envelopes.

Degradation, contamination, and deterioration of many chemicals utilized by the Air Force may occur during storage. From a long list of such chemicals are oils, greases, preservation fluids, desiccants, solid and liquid fuels, fire extinguishing agents, antifreeze solutions, cleaning and decontamination solutions, and nondestructive test media used for magnetic particle and fluorescent penetrant inspections. Contamination of one fire-extinguishing material (bromochloromethane, for example) results in free acid solutions. Undoubtedly, several of these compounds will be present in the silo and may add to variables in the environment.

Types of Corrosion to Be Encountered

Chemical Corrosion

Chemical corrosion, rusting, does not normally occur unless there is at least a 40 percent relative humidity. Of primary concern is gross chemical corrosion that actually weakens a metal part by simple deterioration. In a missile system, however, components are built to extremely close tolerances, with sensitive parts on which even an invisible amount of oxidation might cause a failure. Since corrosion is an accumulative process, it is not pertinent to say that over a course of x months the average humidity was well under 40 percent. Each time the humidity exceeds a particular percentage, whatever this might be for the system involved, there is an immediate reaction and the corrosion process begins. Whatever oxides are formed remain as oxides. The next time corrosive conditions occur, the new corrosion is additive to the initial corrosion. The effects of corrosion must be evaluated on the basis of integration of all the corrosion that might have occurred since the part was stored.

The effect of combinations of moisture with other compounds in the air—e.g., ozone—on glass fibers and reinforced plastics must also be analyzed. Contrarily, consideration must also be given to the effect of low humidity on cellulose materials, impregnated paper, etc. It is possible that humidity levels which would ensure high reliability in metal parts might cause failure of a missile because of dried-out parts that needed a minimum amount of moisture to hold their basic form.

Galvanic Corrosion

The possibility of galvanic action between dissimilar metals is too well known to require further discussion. It is also common knowledge that the potential of any one metal or alloy differs widely, depending on the environmental conditions. But it bears repeating that the potential of a metal in the electromotive force series is only a rough guide to its galvanic behavior in any specific environment and that its potential is reversible.

Localized Corrosion

A metal may develop pits or blisters at local areas, or it may be attacked selectively at grain boundaries or along slip planes. In the case of a two-phase alloy, one phase or constituent may be attacked selectively, while the other(s) is completely resistant. The occurrence of localized corrosion often makes it difficult to evaluate the true extent of the damage. Localized corrosion can result from conditions of exposure, as well as from the metallurgical structure of the material.

Stress Corrosion Cracking

Stress corrosion cracking occurs in many materials and is often quite

baffling. A structural part may fail in service at a stress which is considerably below its known yield strength. Stress corrosion cracking is not confined to any single type of material and is not limited to any one kind of corrosive medium. It is well known that carbon steel is affected by certain caustic solutions, stainless steel by acid chlorides, aluminum and magnesium by sea water, plastics by certain solvents, copper alloys by ammonia, and rubber by oxidation.

Any discussion of corrosion would be incomplete without consideration of the effect of temperature increases on the rate of corrosive reaction. Accelerated corrosion may be anticipated when silo temperatures are above maximum. Moreover, warm air is capable of containing a greater amount of water.

Preventive Measures

Protective Coatings

Widely employed systems of sacrificial protective coatings for preventing corrosion of metals need little amplification. Cadmium and zinc platings are of course now mandatory for galvanic metal coupling in missiles. The conventional zinc chromate primers, the various anodic and chemical conversion films and coatings for the aluminum and magnesium alloys, and epoxy resin systems have proved resistant to corrosion under various exposure conditions of media, humidity, temperature, and time.

Sealing of Silo Walls

Consideration must be given to materials for sealing the walls of a silo. Organic coatings can now be applied in the field in heavier thicknesses with fewer coats than was previously possible. Hot spray vinyls, catalyst-cured phenolics and epoxies, epoxy-modified phenolics, and high-build alkyd coatings provide satisfactory protection for a wide range of metal, concrete, and masonry surfaces. Several of the coatings afford good resistance to mild acids and alkalies.

Breathing

A method of breathing for the silo cavity must be provided for pressure equalization. Silica gel beds or similar techniques have been perfected for storage tanks and mothballed ships. Such apparatus could be used as an interface device to exclude moisture and still permit breathing. The use of machinery to maintain a dry atmosphere is the superior method. Linde's "molecular sieve," the "electrodryer," or condensing cooling systems are all proved methods for removal of any quantity of moisture from air. Conventional refrigerated-type dehumidification systems would be the most suitable, especially since they would be compatible with blower-driven air circulation. Temperature-control equipment would also be required to aid the air-conditioning system.

Detection Techniques

Because all sources of corrosion cannot be predicted, preventive measures cannot be assumed to be 100 percent efficient. It must be presumed that deterioration commences the moment the missile is stored. Detection techniques are therefore mandatory to determine the extent of deterioration as it proceeds.

Visual System

The visual system of detection cannot be automatized; it depends upon the individual actually inspecting the missile and ground equipment to determine whether or not corrosive reaction has occurred. Although this method has the advantage of simplicity and low cost, a disadvantage is that inspection cannot be accomplished automatically. In time of crisis, there is no central point to which the information can be transmitted for immediate evaluation.

One category of visual inspection is the chemical type in which silica gel changes color when the humidity rises above a particular percentage. This chemical technique does not indicate corrosion; it indicates, rather, only a humid atmosphere. Since it is in equilibrium with the atmosphere, it indicates only the quality of the atmosphere at the instant of inspection.

A second and superior type of detection is a thin metal film, using a molecularly thin coating of metal on glass or some other substrate. The film corrodes very easily, revealing an integrated history of the corrosive atmospheres. Being inexpensive, a large number of these thin film visual indicators can be placed throughout the missile-silo area.

Electrical Systems

There are various electrical detection techniques that require lead wires extending from the silo to a central monitoring station. Continuous reading or recording can then be made of humidity or the rate of corrosion occurring within the silo area. There are two basic types of electrical measurement which are somewhat analogous to the two types of visual system. One analyzes the atmosphere and helps to determine whether or not it may be corrosive. The second type actually measures the extent of corrosion occurring in a metal specimen. In the first category are the widely known humidity or water vapor measuring devices, such as those made by Consolidated Electrodynamics, Beckman Instruments, and American Instrument Co. Such devices would undoubtedly be valuable in monitoring systems to make certain that dynamic mothballing machinery is operating as it should.

Corrosometer

A second type of detector measures the actual progress of corrosion on a metal specimen. The Corrosometer method uses an exposed thin metal film specimen to measure the increase in resistance of the specimen as the metal is converted from pure metal to oxide.

The measurement of electrical resistance has long been used[1–9] to determine the extent of corrosion on metal specimens. Only recently, however, has work been done to develop a method which would find use in measuring corrosion in a variety of industrial processes.[10–13] Even more recently,[14–16] an Air Force program was initiated for the development of both visual and electrical thin metal film integrating corrosion indicators for storage applications.

Readings are made directly on metal specimens without their removal from the corrosive medium. These readings are essentially independent of the temperature and nature of the corrosive medium. The method appears to be the most efficient developed to date. (A detailed description of the present state of development of this method is presented in references 15 and 16.)

Possible Environment Control and Monitoring for Complete Silo Complex

The control and monitoring of a particular silo complex will vary with locale, climate, and other environmental conditions. A hypothetical equipment setup for a typical installation is presented in Table 2. Some, or all, of the recommended detection techniques may be applicable; all are worthy of examination. For monitoring purposes, remote indicating devices at the control points appear to justify fully the additional expense involved. Economy cannot be permitted to decrease the reliability of an expensive missile-silo system.

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[10] Bureau of Mines, *Fires, Gases, and Ventilation in Metal and Non-Metallic Mines*, Miners Circular, Vol. 55, Jan. 1955.

[11] Mowers, R. E., *How the New Propellants Affect Plastics and Elastomets*, Materials in Design Engineering, Sept. 1959.

[12] Logan, K. D., *Underground Corrosion*, U.S. National Bureau of Standards Circular, C-450, 1945.

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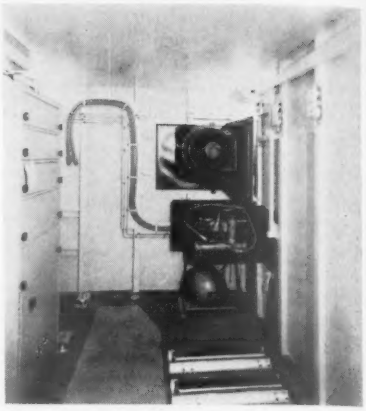

Fig. 4. View similar to that of Fig. 2, but without console in position, showing heat exchanger and air compressor stowed for shop transport, and air reservoir, bottom.

Hawk Field Maintenance (Continued from page 37)

Table 1 shows some of the operating characteristics of the hydraulic console.

Heat Exchanger

The heat exchanger is mounted on a hinged utility door. For transport, the door is positioned so that the unit is secured internally. When emplaced, the door is swung outside the shelter and locked in that position allowing more efficient operation of the heat exchanger and, incidentally, reducing the noise level inside the shelter. Flexible hydraulic hoses and electric cables permit free movement of the hinged door from the stored to the operating position.

The heat exchanger, an air-to-oil type rated at 600 Btu/min, is used to control oil temperatures in the hydraulic console. In normal operation all oil used for tests circulates through the heat exchanger.

Operation of the unit is controlled by a thermostatic switch located in the main reservoir of the hydraulic console. This switch activates a 416-vac, 400-cycle, 3-phase motor which drives a cooling fan. The fan is started at oil temperatures of approximately 100°F and shuts off at approximately 80°F.

Air Compressor and Reservoir

The air compressor and the air reservoir assembly furnish a supply of compressed air to the degreaser and accumulator test console for various test purposes. A pressure switch is provided on the air reservoir assembly limiting the maximum charging pressure to 2,100 psi. The compressor also supplies air for charging the hydraulic accumulator in the hydraulic console. The unit is mounted on a hinged utility door for more efficient operation.

The Kidde air compressor, rated at 4 standard CFM, at 3,000 psi, at 3,750 rpm, is driven by an integrally mounted 416-volt, 400-cycle, 3-phase electric motor and gear box. The compressor is a 4-stage, intercooled unit. A relief valve on the intercooler between the first and second stages is set at approxi-

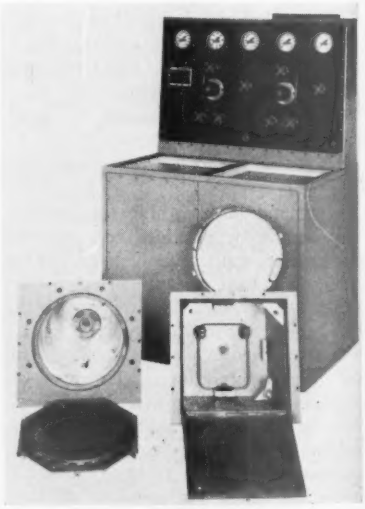

Fig. 5. Hydraulic test shop degreaser and accumulator test console with degreasing tank and accumulator tank removed.

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Table 1. Hydraulic Console—Technical Data

Dimensions	
Height	70 in.
Width	78 in.
Depth	28 in.
Operating Characteristics	
Motor	19 hp, 416 vac, 3ϕ 400 cycle
Pump	8 gpm at 3,000 psi, variable displacement
Operating pressure	Up to 3,500 psi
Pressure relief, system setting	3,900 psi
Flows (MIL-H-5606 Oil)	Up to 8 gpm
Reservoir capacity	20 gal
Temperature, operating (thermostatically controlled)	−10 to 125°F
Motor off (thermostatically controlled)	175°F max
Air-to-oil heat exchanger (thermostatically controlled) (external to hydraulic console)	600 Btu/min
Overload circuit breaker	50 amp
Service panel voltage	28 vdc
"Low" flowmeter	Up to 2 gpm
"Hi" flowmeter	Up to 9 gpm
Static pressures (hand pump system)	Up to 6,000 psi
Other Design Features	
Shock	15*g*, 11 millisec
Vibration	6 in. double ampl. 1–3 cps; 4*g*, 4–300 cps
Quick disconnect porting	
Leakage graduate test panel	
Timer panel	
Switch (panic) panel	

Table 2. Air Compressor—Technical Data

Capacity	4 SCFM (0.31 lbs/min) with inlet of 29.92 in. of Hg abs. at 60°F
Operating pressure (max)	3,000 psig
Shaft speed	3,750 rpm
Heater power	28 volts, 3.6 amp
Power Requirements	3-phase, 400-cycle a.c.
(a) 208-volt operation	
(1) Running (normal)	15.7 amp
(2) Locked rotor	68.5 amp
(b) 416-volt operation	
(1) Running (normal)	7.8 amp
(2) Locked rotor	34.2 amp
Special Features	
Vibration (MIL-E-5272 Para. 4.7 Procedure I)	
(a) Motor—Explosionproof (MIL-E-5272 Para. 4.13.1 Procedure 1)	
(b) Moisture separator—Contains heater and safety disc, pumps moisture, and purges line to compressor when compressor stops	
(c) Check valve (MIL-V-8628)	
(d) Back pressure valve—Maintains minimum pressure of 1,550 psig through moisture separator	
(e) System relief valve—Relieving pressure, 3,500 psig max Reset pressure, 3,100 psig min	
(f) Filter—Inlet to first stage of compressor, 40 microns	
(g) Chemical drier—Chemical drier housing with replaceable cartridge	

mately 675 psi. A system relief valve after the fourth stage is set at 3,450 ± 50 psi. Table 2 lists detailed technical data of this compressor.

Degreaser and Accumulator Test Console

The degreaser and accumulator test console (Fig. 5) performs three main functions: (1) Provides a pneumatic supply, (2) charges accumulators, and (3) provides degreasing facilities.

With the use of valves and flow compensating pressure regulators, air pressures ranging from approximately 50 to 3,000 psi can be supplied to any of three quick disconnect fittings on the front panel of the console. Pressure is also supplied to an accumulator charging fitting. Pressures at these supply points are indicated on gages located on the front panel.

A degreasing tank, built into the console, provides a cleaning facility for the test shop. Low-pressure air can be bubbled through the degreasing fluid for cleaning purposes. Solvent fumes are vented through an outlet from the degreasing tank to the outside of the shelter.

Field maintenance equipment for Hawk Missile Systems of the type described in this article have been in production at Kidde Electronics Laboratories since early 1960. The equipment is now operational and field usage has shown it to be highly reliable.

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In-Flight Fire Control Evaluation (Continued from page 31)

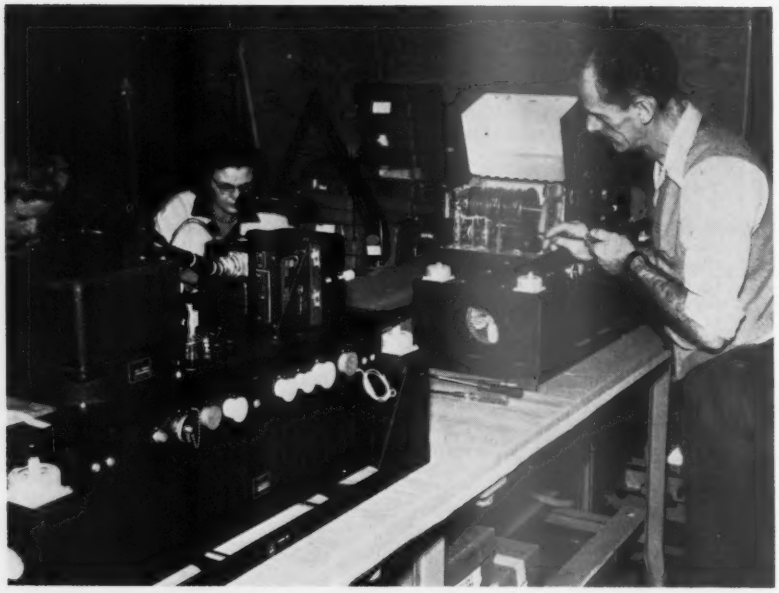

Fig. 1. Final adjustments are made to fire control operator evaluator before Air Force acceptance inspections. It weighs about 108 lbs and occupies a space of over 4 cu ft ($33^5/_8$ by $16^7/_8$ by 13 in.). In the foreground is a fire control system evaluator, identical in size but weighing only 65 lbs.

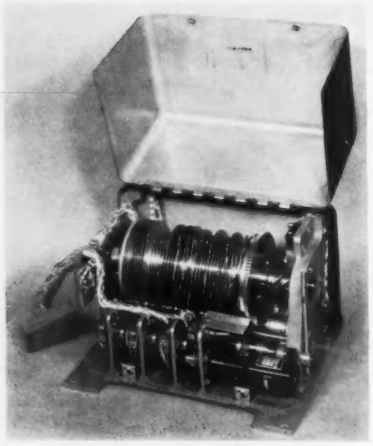

Fig. 2. Cam programer.

search, programed azimuth and elevation signals are compared in coincidence circuits with positional signals from the system's search antenna. Coincidence causes sync pulses to be generated through gating circuits to a video generator where the time relationship is controlled by programed range. The video generator, in turn, feeds these delayed sync pulses as video signals into the display circuits of the radar, thereby activating the radar indicator.

In acquisition mode, a miniature servo within the evaluator is used to repeat the turrent position as controlled by the gunner. Its output is compared with phantom target position and, when coincidence in both axes within the lock-on cone is achieved, the track radar locks onto the phantom target. Accurately controlled trigger and coincidence circuitry is necessary for this operation.

In track mode, the same servo represents programed target position and drives the turret in a closed loop, thereby duplicating normal action of the track antenna in holding the target. If the gunner overcontrols the turret and loses lock-on, this is recorded as a gunner error.

Unlimited Programing

The programer used in this equipment consists of

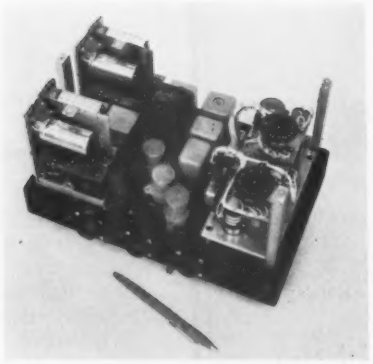

Fig. 3. Uncovered view of automatic aerial harmonization unit which weighs 13 lbs and measures $11^1/_4$ by $7^1/_4$ in. The unit utilizes the trackshot technique upon which operation of the system evaluator is based —measurement of the angular miss of the fire control system by detection of projectiles as they pass through a predetermined range. The radar error signal developed from the radar echoes is used to offset a potentiometer mounted on the output shaft of an integrating servo. The a.c. output of the potentiometer is fed as a bias to the track radar antenna servo, which offsets the antenna by the amount of the angular miss. This in effect changes the position of the guns in space to cancel the miss angle.

a series of separable helical cams grouped on a common shaft to form a five-turn spiral. Complete target information of azimuth, elevation, range and correct action for single and multiple attacks is cut on the cam periphery.

This type of programer is so designed that individual cams, when grouped together in the current magazine 7 in. long and $3^1/_2$ in. in diameter, form a continuous spiral cam surface of 31 ft in length (Fig. 4). Individual cams may be shuffled on any one shaft to provide an unlimited variety of presentations to the gunner. For example, cam magazines furnished with the present equipment allow for 80,000 different target attacks. Each magazine is quickly disengaged for replacement by other cam magazines. In this manner, the cams can be grouped to present varying levels of target attack complexity to the gunner.

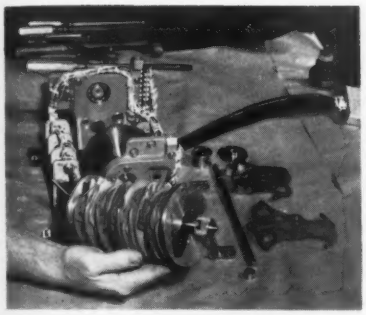

Fig. 4. Assembly of function cam magazine reveals details of its construction. The programer's cams are so designed that individual cams, when grouped together, form a continuous spiral. Since the axial motion of the magazine is the same rate as the cams, a single follower "sees" a continuous cam periphery presented to it by a succession of cams.

Tested Evaluators Accepted

The Air Force accepted the evaluators for operational use only after extensive flight-testing in the operating environment. Although these particular units are tailored to a specific fire control system, application to another radar-controlled gunlaying system is merely a problem of converting inputs through an adapter unit. Potential applications of this evaluation equipment extend to any radar-controlled, gunlaying fire control system. The techniques are also applicable to shipboard and land-based heavy gun systems. It is entirely feasible to adopt the approach used in the operator evaluator to any system which employs an operator who is required to make a decision when monitoring his machine. Possible commercial applications exist in the fields of machine tool control, process control and in the training of airport control tower personnel.

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Operation Non-Routine

(Continued from page 39)

proves that we actually have greater loads than can be measured by present techniques.

Conclusions

It is every bit as important to achieve maintainability and reliability as it is to obtain the Mach 3 performance. The economics of a Mach 3 airplane are based on the realization of three times the productivity of the present subsonic machines. If this objective is not realized, it probably will result in economic disaster for the airline and possibly for the specific airframe manufacturer. It is imperative that the next generation of air transports be designed with reliability and maintainability on equal basis with the speed performance requirements. Quick and effective handling of Operation Non-Routine must be achieved to assure success of the supersonic airplane.

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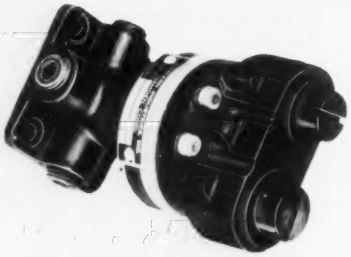

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Check these Eastern gear pump features — do they suggest a solution to your present design problem?

Small size: Eastern gear pumps are the smallest, lightest made. Airborne servo system pump shown delivers 1.5 gpm @ 1500 psig — measures only 1⅞" x 1⅞" x 2¾", weighs 9 oz.

Wide performance range: pumps available have theoretical displacement from .0016 to 1.300 cu. in. per revolution — flow from .025 to 9.6 gpm, pressures from 0 to 2000 psig, at speeds to 24,000 rpm. Weights with motor range from 1.5 to 8.5 lbs.

Unaffected by extreme environments: rugged, reliable Eastern units take loads to 50g in stride — shrug off temperature differentials to meet MIL specs.

Flexibility, economy: mass-produced components can be teamed into the precise configuration you need. Creatively engineered custom pumps also available. *Check the choices by writing for NEW BULLETIN 370 AEC.*

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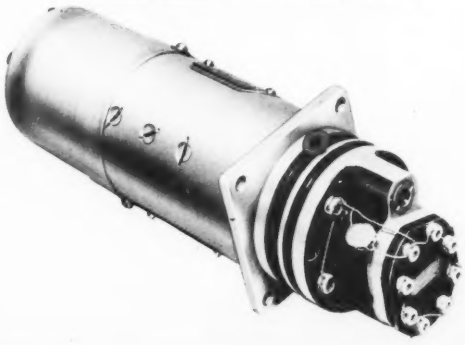
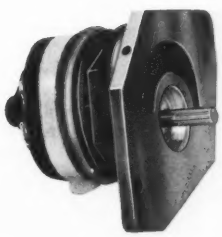
Craft: (top to bottom) B-47, KC-135 (tanker), B-58, B-52G firing Hound Dog

This pump provides necessary hydraulic power to the fuel control system during starting of an accessory turbine.

Under extreme temperature and pressure conditions, this pump powers oil well surveying equipment deep within a well.





An integral part of an APU system this unit provides hydraulic power to a missile.

Missiles: Left to Right, Little John, Hawk, LaCrosse, Nike Zeus

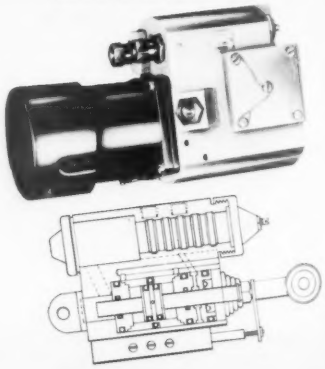
EASTERN SERVO SYSTEMS include servo valves, amplifiers, fuel controls and actuators — provide brain and brawn in many advanced missile systems. **Typical assignment:** design and develop a missile elevon control servo with a single hydraulic power supply and three actuators. Weight and space considerations critical.

Solution: a system designed and built around the Eastern E/HS 5 type 100A hydraulic power supply, using a 400-cycle motor. Minus motor, but including pump, reservoir, expansion chamber, pressure regulating valve and filter, the supply weighs only 2.6 lbs.

Eastern achieved a 20% saving in hydraulic power supply capacity by the use of one of its own *pulse length modulated* single-stage servo valves, manifolded to each actuator. Zero first stage leakage, zero hysteresis, plus the high response and efficiency which characterize this valve contributed to the successful meeting of the demanding requirements.

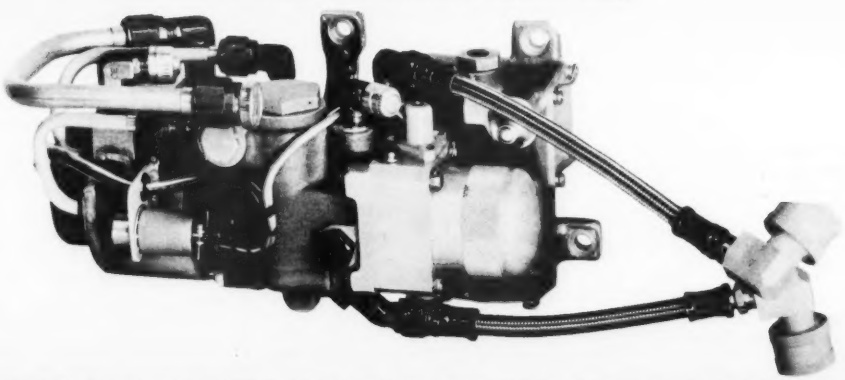
For full information on Eastern servo capabilities, write for ELECTRO-HYDRAULICS BULLETIN AEC and for genuine contributions to the solution of your servo problems, call in the Eastern engineer.

Hydraulic power pack for missiles.



(Foreground, left-to-right): Pershing, Sergeant, Honest John, Nike-Ajax (before and after firing). (Background): Redstone, Nike Hercules (in flight), Corporal

Electrohydraulic servo system for magnetron tuning.



MISSILES AND MISSIONS

One-man missiles:

1. Cobra
2. SS 11
3. Davy Crockett*
4. Redeye

Tactical surface-to-surface missiles:

5. LittleJohn
6. LaCrosse
7. Mace
8. Sergeant
9. Honest John
10. Pershing

Air-to-surface missiles:

11. Hound Dog
12. Quail
13. Skybolt*
14. Bullpup

Ground-to-air missiles:

15. Terrier
16. Nike-Hercules
17. Tartar
18. Hawk
19. Mauler
20. Talos
21. Bomarc
22. Nike Zeus

Air-to-air missiles:

23. Genie
24. Sidewinder
25. Three Falcons
26. Eagle*
27. Sparrow III

Undersea missiles:

28. Astor
29. SUBROC
30. ASROC

Strategic surface-to-surface missiles:

31. Atlas
32. Titan II*
33. Thor
34. Polaris
35. Minuteman

Spacecraft boosters:

36. Agena B
37. Centaur (second stage)
38. Atlas/Mercury
39. Thor AbleStar
40. Thor Able
41. Scout
42. Saturn

* (artist's impression)

EASTERN RESEARCH and DEVELOPMENT -- A continuing program of research has made it possible to develop units to solve the new problems incurred with the expanding performance requirements of the new missiles and spacecraft. We are continually extending the uses of the latest Eastern units in electronic tube cooling, pressurizing electronic equipment, pumping fuels and hydraulic fluids, supplying hydraulic power and electro-hydraulic servo systems.

Our facilities are extensive for this specialized work. Research and testing laboratories, model shops, and three manufacturing plants provide the specialized equipment and manpower to turn out fully qualified units to meet appropriate government specifications.

We solicit direct inquiries. From our extensive line of existing units, adaptations of these units, or completely new designs, we can assure every possibility of providing equipment to handle your project satisfactorily.

One or more of these brochures contain technical information

HYDRAULIC PUMPS *This new catalog is an invaluable directory to no less than 129 pump-and-electric-motor-combinations — any and all available off-the-shelf!*

Searching for gear pumps with top volumetric efficiencies? Do your performance requirements fall into one of these three major groups?

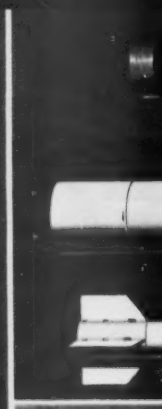
- Eastern 1200 series — up to 1.6 gpm — pressures to 800 psi
- Eastern 100 series — up to 5 gpm — pressures up to 1500 psi
- Eastern 700 series — up to 9.8 gpm — pressures up to 1500 psi

If one or more of these performance ranges measures up to what you need, save hours of searching your way through the gear pump maze — send for catalog 810 now!

...ipment. Send for them now.

...AL PUMPS If you need centrifugal pumps ...aracteristics, this reference book is for you: • ...to 21 psi in single stage pumps; to 70 psi in multi-... FLOWS: capacities to 70 gpm in single-stage ...gpm for multi-stage models. • MOTORS: standard ...15/230 volts 60 cycles 1 phase (other electrical ...available). Power range from ⅛ to 1½ H.P. • ...S: drip-proof, totally enclosed, and explosion-...ing frames. • DRIVES: space-saving close cou-...ost rugged and popular. Pedestal mounted ar-...hout motor available as alternate for belt or ... • SEALS: a variety of rotary seals and stuffing ...ery application. • METALS: your option of cast iron, bronze, stainless steel, Monel, Cast Iron, Hastelloy "C". • INSTALLATIONS: a wide range of transfer, recirculation, feed, boost and filter-pumping applications. All told, 50 different models are described in full — and you get a wealth of technical data as well. Write for new catalog 130 now!

QUICK-DISCONNECT COUPLINGS are on review here — *both* in off-the-shelf and custom-designed units — and the *best* in both. Eastern miniature quick disconnects for electronic tube cooling, and other critical pressure drop situations are the smallest units available for both high and low pressure systems. Complete specifications, tables, diagrams — yours to keep for quick reference in the brand-new Eastern catalog 910.



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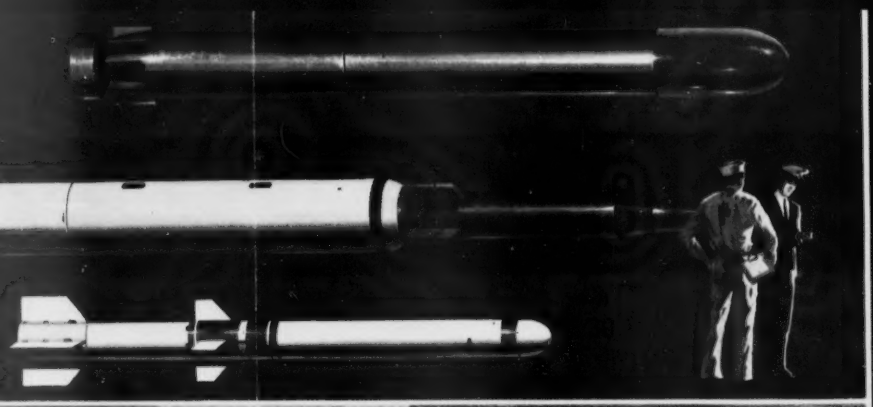

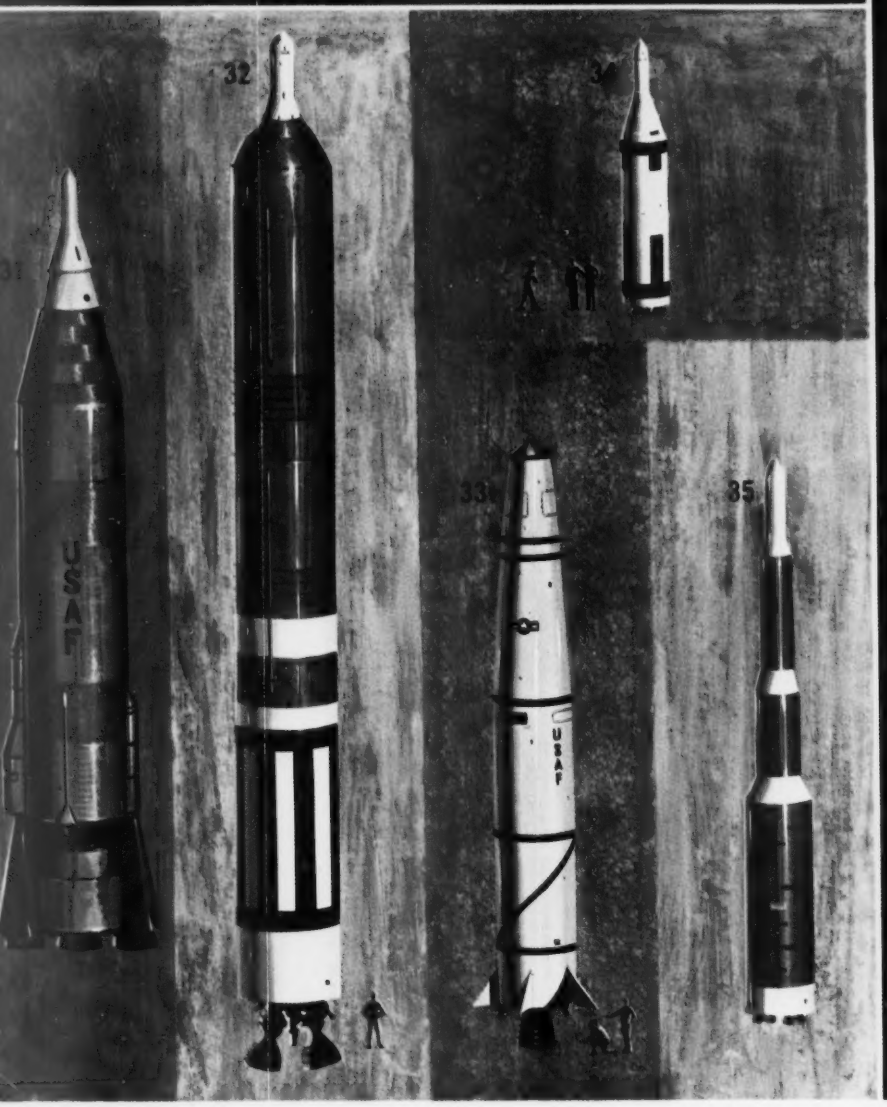

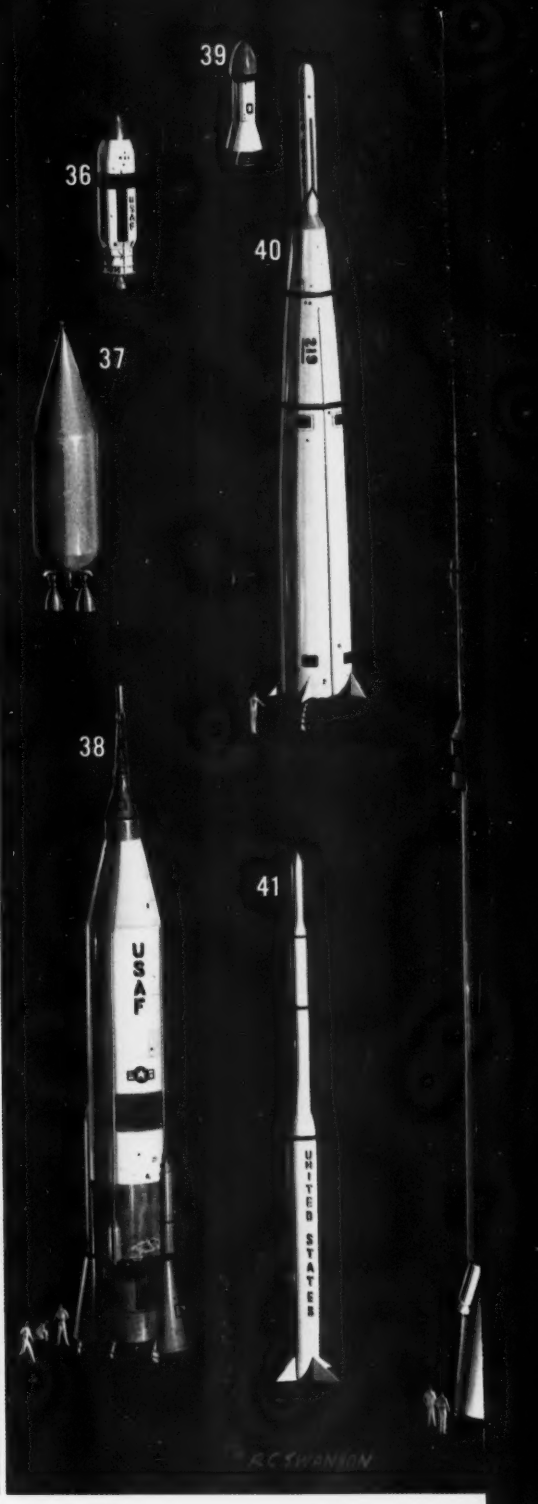

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Eastern AVIATION PRODUCTS

EASTERN INDUSTRIES
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West Coast Branch Office: 4203 Spencer St., Torrance, C

Missiles: Bomarc (close up) and Genie (above) and Falcon (below)

—55 to
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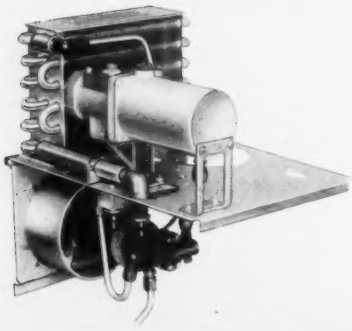
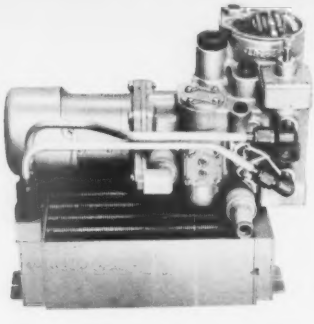
cost-saving
Write for

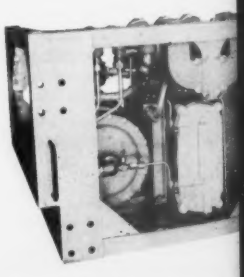
This unit cools aircraft electronics — operates to 60,000 feet.





Compact missile cooling system.

Shipboard cooling system capacity of 12,500 watts.



Right Top: Mauler, Below: T-55 (Chemical Launcher), Foreground: SS-11 (anti-tank), On Jeep: Davy Crockett Launcher

EASTERN ELECTRONIC COOLING PACKS for electronic subsystems extend operating ranges to altitudes where air cooling becomes ineffective. 'Black box' designs can be more compact — reliable even at five times the speed of sound.

These liquid cooling systems are completely self-contained — provide such components as pumps, heat exchangers, air impellers, reservoir, coolant flow and temperature interlocks and similar parts.

Cooling capacities of existing systems range from 250 to 25,000 watts dissipation rates. Eastern cooling packs take ambient temperatures from —55 to +71°C in stride, and perform to altitudes of 70,000 ft.

Extensive experience in missile applications has enabled Eastern to develop systems unusually compact and light as well as highly reliable. At the same time, Eastern is able to provide at minimum cost equipment engineered to a specific need by using missile-proved components designed to your system configuration.

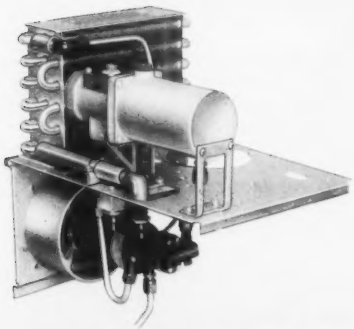
Turn to Eastern for space-, weight-, and cost-saving solutions to your hottest cooling problem. Write for NEW BULLETIN 370 AEC.

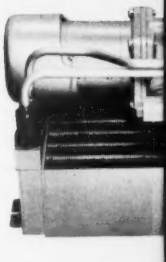
Missiles: Bomarc (clo

This unit
operates

les: Bomarc (close up) and Genie (above) and Falcon (below)

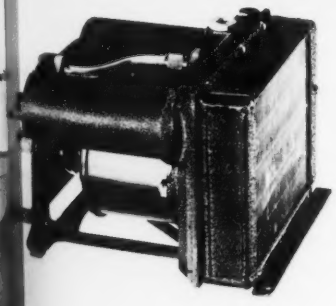
This unit cools aircraft electronics — operates to 60,000 feet.





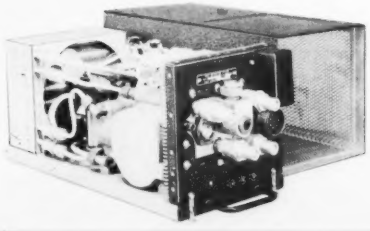
Compact missile co

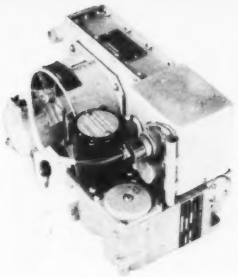
(top) F-104 with Sidewinder, F-106 (below), F-102.



Avionic cooling pack with 250 watts capacity.

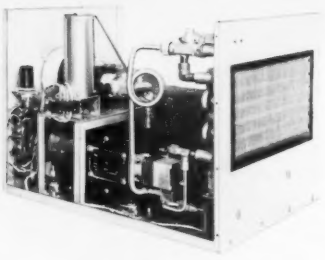
A dual cooling system with two complete flow paths.





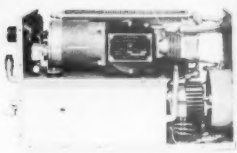
Flexible hydraulic coolant pack.

Missiles: Polaris, Tartar



Aircraft refrigeration pack weighs only 45 lbs.

Refrigerated air supply designed as an integral part of an aircraft electronic check-out assembly.



Airborne refrigerated liquid cooling system.

Missiles: (top) Subroc, Asroc (left), Talos (foreground)

EASTERN REFRIGERATED COOLING UNITS offer temperature control within close limits to protect sensitive aircraft and missile components and systems while ambient temperatures fluctuate widely. Eastern refrigeration-type cooling systems are ideal for such conditions.

Designed for the strictest military requirements, these vapor-cycle closed-system packages are built around a highly efficient compressor powered by a special 400-cycle motor. Unique condensing and special cooling methods are called upon to meet the most unusual operating requirements, the most demanding specifications.

Capacities range from 100 to 6000 watts; operating altitudes extend to 100,000 feet. Some units, of the "boil-off" type, perform almost without regard for extremes in altitude and temperature.

Call on Eastern for imaginative solutions to refrigeration cooling problems . . . and write for ***NEW BULLETIN 370 AEC.***

Missiles: (top left) Redeye, (top right) Nike Zeus, (lower left) Skybolt, (lower right) Titan II.

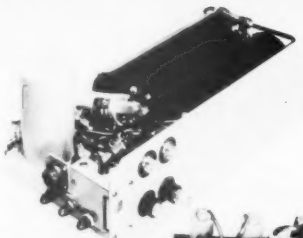
EASTERN DEHYDRATION & PRESSURIZATION SETS are made to the measure of the advanced avionic systems of tomorrow. Whenever a precisely controlled flow of dry, pressurized air is required, Eastern design and production experience team up to create compact, lightweight, reliable subsystems.

Characteristics and performance range of existing units:

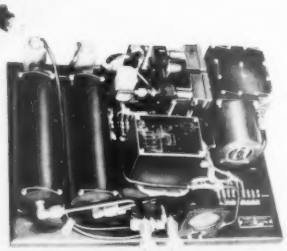
- **capacities: up to 3.0FT³/Min. free air**
- **operating temperatures: from -67°F to +165°F**
- **operating altitudes: from sea level to 50,000 ft**
- **weights: as low as 4 lbs.**

Smaller packs feature replaceable chemical dehydrator elements — the larger subsystems are available with automatic reactivating dehydrators.

Let us quote on your next pressurization/dehydration requirement. In the meantime, write for full information on the entire line of Eastern aviation products. Send for ***NEW BULLETIN 370 AEC.***



Dehydration pack for Nike Hercules radar wave guide.



Pressurization unit with automatic regenerative dehydrator.

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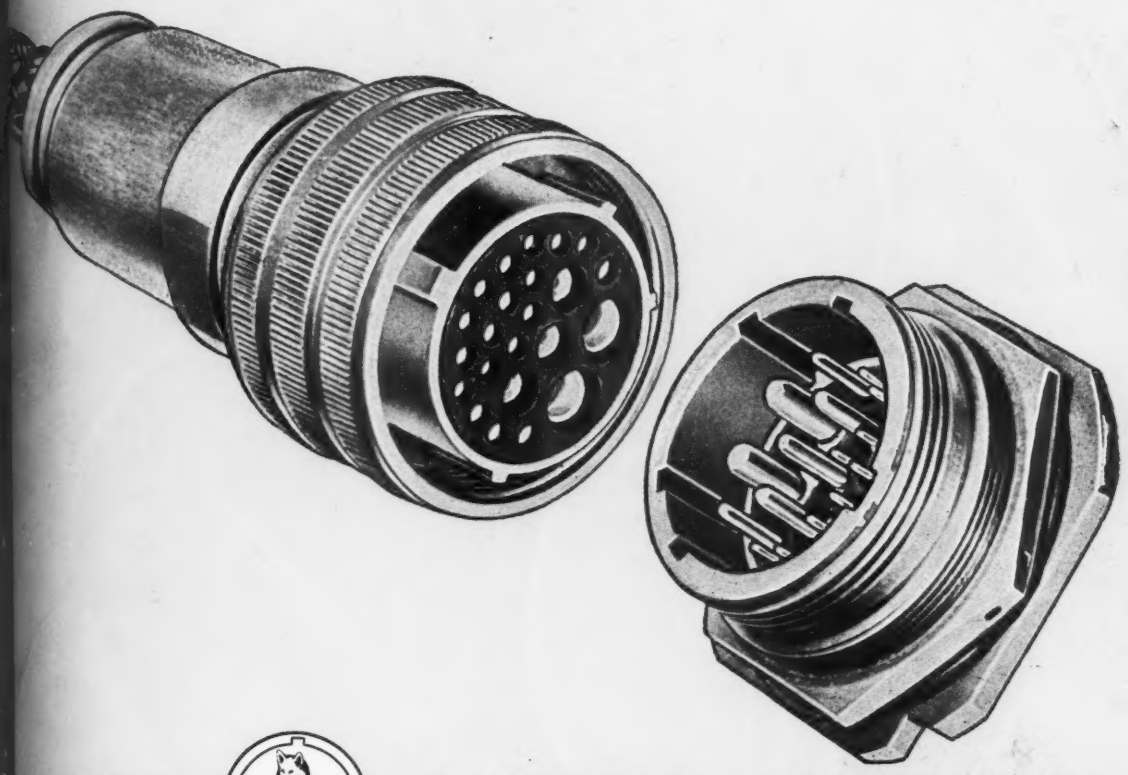
NEW FROM BENDIX



QWLD ELECTRICAL CONNECTORS

FOR MISSILE GROUND SUPPORT EQUIPMENT

WITH SUCH OUTSTANDING ADVANTAGES AS:

FIVE INTEGRAL KEYS AND KEYWAYS that provide for positive polarization and positive mating—even in blind locations. ***No possible contact damage.*** QWLD connectors can be fully mated and unmated by hand.

HEAVY-DUTY CONSTRUCTION through use of extra-heavy machined or forged aluminum shell components, resilient inserts, silver-plated copper alloy contacts, and rugged cable accessories with new superior gasket design.

TWO NEW SERIES AVAILABLE with the QWLD having standard solder or solderless contacts and the QWLG having provisions for grounding one contact to the shell.

PLUS . . . IMPROVED WATERPROOFING • CLOSED ENTRY SOCKET CONTACTS • SELF-EJECTING COUPLING ACTION • DESIGNED TO MEET MILITARY SPECIFICATIONS • WIDEST RANGE OF CABLE ACCESSORIES.

QWLD is the latest development in Scintilla's long line of multiple conductor cable connectors—and is specially designed to meet the rugged environmental conditions of missile launching equipment, ground radar, or power and control circuits—and heavy-duty industrial applications such as are found in oil fields or mining. Be sure to investigate the new QWLD HUS-KEY* Connectors from Scintilla.

*TRADEMARK

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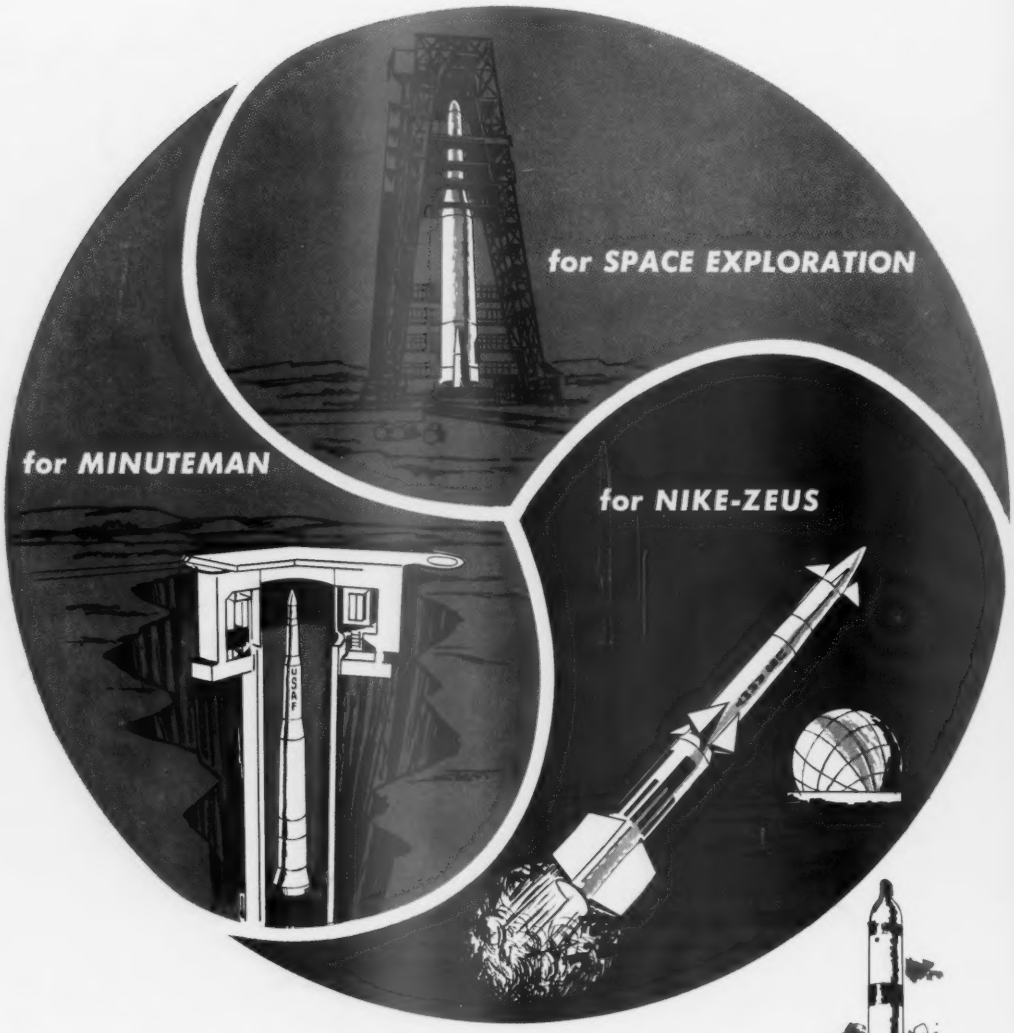
Look to Parsons for Performance
IN MISSILE AND ROCKET FACILITIES



...and for TITAN II, *too...* (*see front cover*)

This kind of experience has built Parsons' reputation for total capability, single source of responsibility.

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